EDWARDS & WELLS

Automobile Mufflers

Mechanical Engineering

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AUTOMOBILE MUFFLERS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN ISAAC EDWARDS and REGINALD ELLIS WELLS

ENTITLED AUTOMOBILE MUFFLERS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

CONTENTS

PART I

AUTOMOBILE MUFFLERS

PRELIMINARY REMARKS

Since automobiling has become general and machines of all types are so numerous throughout the whole country, the muffling of the noise together with the elimination of the smoke and stench arising from the exhaust gases has become one of the important problems in connection with the use of the gasoline engine as the motive power. These conditions are essential not only to the user of the automobile from the point of comfort, but to the passers by from a point of safety and security. Some countries have even gone so far as to place owners of machines with noisy or smoky and ill-smelling exhausts, liable to a fine or imprisonment.

The design of mufflers, though American made, can hardly come under the terming, "American Practice". It would seem that this is the one part of the automobile, on which the maker feels free to exercise his individuality at whatever reduction of efficiency of the machine. The aim seems to have been in most cases to reduce the noise of the exhaust, and the reduction of power has usually been considered as secondary. That the muffler as ordinarily made reduces the power of the engine is commonly understood, and most manufacturers allow for this by placing cut-outs on their engines. Im this way the maximum effort of the engine may be utilized when needed most, as in ascending steep grades or traveling at high speed.

The manufacturers have succeeded in reducing the noise to a considerable extent in most of the high grade American cars. It is to this end that their attentions have been directed almost from the beginning of the automobile industry. The time has now come where back-pressure due to the muffler will be the point of most serious consideration.

The makers of mufflers are widely at variance as to the best proportions to use in the same style of muffler. Many instances can be cited, where, in the same type of muffler, different makers use designs just the reverse of each other.

PURPOSE OF THESIS

1. - Description of Various Types of Automobile Mufflers.

To show the different practice in the design of automobile mufflers, the endeavor was made to obtain the constructions and dimensions of as many different kinds of mufflers as possible.

2. - Tests of Some Commercial Types of Mufflers.

The object of the tests was to investigate and determine if possible the effect of the muffler on the work of the engine, and to obtain if possible as a result of the tests the most economical means of muffling the gas engine.

DESCRIPTION OF VARIOUS TYPES OF AUTOMOBILE MUFFLERS.

The main purpose of the automobile muffler is to reduce the noise of the exhaust gases issuing from the motor. When no muffler is used, the gases are expelled from the exhaust ports of the engine at a pressure somewhat above that of the atmosphere and with considerable velocity. This produces a very sharp, disagreeable report. The muffler also eliminates the smoke and stench of the exhaust to a great extent.

The noises of the exhaust may be reduced by,

1. - Breaking up the body of the gas into a number of fine streams.
2. - Allowing the gases to expand and cool.
3. -- Checking the velocity.
4. -- Reducing pressure to as nearly as possible that of the atmosphere.

Puttingthis in a different manner, exhaust gases possess a certain amount of energy, partly kinetic but mostly potential. This may be absorbed in the following ways:

1. - Lamination.
2. - Friction.
3. - By cooling.

The means employed by the manufacturers to accomplish these

objects will be discussed in the following pages. Owing to the scarcity of literature on the subject of mufflers, it was very difficult to obtain much exact information concerning any special types. Some cuts and designs were obtained from the automobile journals and Cycle and Automobile Trade journal.

With a view of securing the actual dimensions of some of the mufflers used on well-known cars, a trip was taken to Chicago, that being the nearest distributing point of automobiles. We found, after spending several days with the agents and demonstrators of different cars, that the muffler was a mystery to most of them. We were kindly given the freedom of their establishment in nearly every case, but very rarely were we enabled to get at the inside of a muffler, and determine its dimensions and construction. Owing to this fact, our data in some cases are not very exact, consisting mainly of the external dimensions, together with what information we were able to pick up regarding their inner construction.

GENERAL TYPES

According to the method of construction, mufflers may be divided into the following classes.

1. - Those in which the gases are expanded and broken up by passing through a cylindrical chamber containing a number of baffle plates pierced with holes.

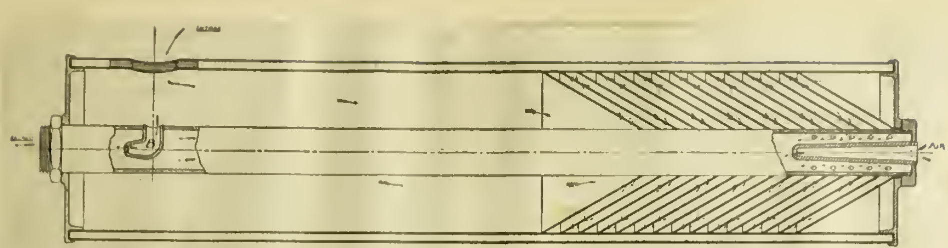
2. - Those in which the gases enter a central cylindrical chamber and are allowed to expand gradually into a series of concentric chambers.

3. - Those in which the gases are divided into opposing streams so as to reduce the impact at exhaust.

4. - Mufflers made on the ejector principle, such that part of the gases are directed through a nozzle thereby causing a partial vacuum in the chamber surrounding the nozzle, and drawing the remainder of the gases through a succession of baffle plates located in the chamber.

5. - Combinations of the above types.

The Ejector Muffler.



MUFFLER MADE ON EJECTOR PRINCIPLE TO GIVE CONTINUOUS NOISELESS EXHAUST.

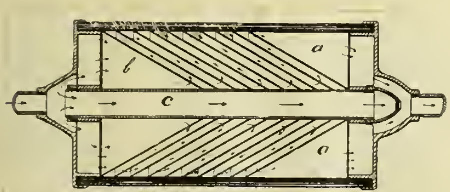
The body of the ejector muffler consists of a cylinder of sheet metal having its ends closed by flanged heads. Through the length of the muffler runs a pipe whose ends project through the muffler heads at each end. Near one end of the pipe, within the body of the muffler, several sheet metal cones are placed, nested one within the other with spaces between. These spaces, together with holes punched through the cones, form a series of tortuous passages through which the exhaust gases must pass before reaching a number of small holes leading into the central pipe. This end of the pipe is closed by a cap, through which a nozzle projects far enough into the pipe to clear the holes which carry the gases from the cones. At the opposite end of the central pipe another nozzle opens from the interior of the muffler into the interior of the central pipe, pointing in the same direction as the nozzle at the opposite end.

The exhaust pipe from the motor opens into the muffler directly opposite the opening of the second nozzle, so that a portion of the gases shoots into the nozzle and into the pipe, creating a partial vacuum in the pipe between the two nozzles

which causes a rush of air through the first nozzle and along the central pipe, mingling with and carrying along the gases as they come from the cones, and cooling them as they pass along to the outlet. The manufacturers claim that the flow of gas is practically continuous, owing to the operation of the ejector principle, eliminating back-pressure and noise.

The body is double, with a packing of asbestos between the sheet steel walls, which are sufficiently heavy to withstand explosions. The cones are thin enough to vibrate slightly and throw off carbon deposits, which would other wise clog the openings.

The Autocar Muffler.



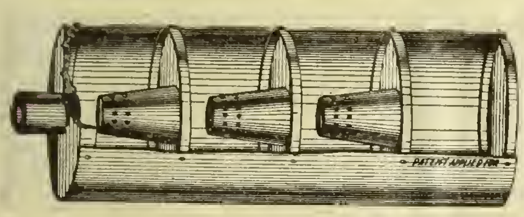
The muffler used on the two-cylinder Autocar is built on the ejector principle as shown in the cut. The walls are double with a packing of asbestos between.

Distributed along at equal spaces are twelve sheet metal cones, in which numerous holes are punched, some in the small and others in the large end of the cone. The action is identical with that described in the ejector muffler. The construction varies a little, in that the nozzle is placed differently.

The number and size of holes cut in the cones seem selected entirely at random. The different areas through which the gases pass are shown by Curve 1 on page 70. It is very evident that a muffler utilizing such areas in the exhaust passages

would necessarily have a large back-pressure. That this was the case is evidenced somewhat by the fact that it had been blown to pieces by an extra heavy explosion in the muffler. If the exhaust areas had been larger and more uniform the muffler would probably have suffered no serious effects from the explosion.

The "Hush" Muffler.

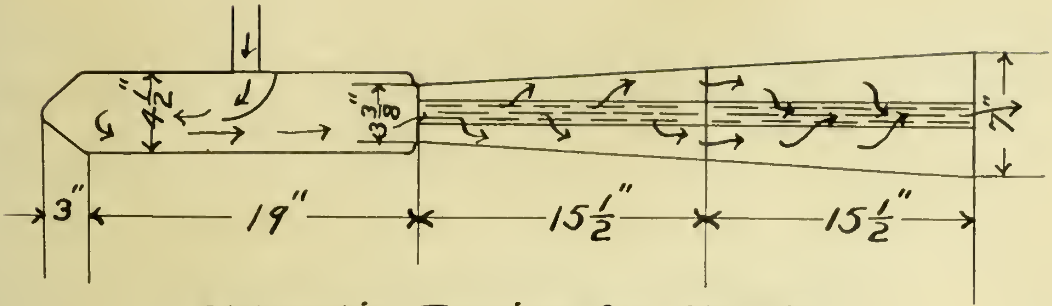


This muffler is made under the McClure-Bochner patents. It consists essentially of a large expansion chamber divided into four equal compartments by baffle-plates as shown in the cut. On these baffle plates are set sheet metal cones with holes punched around the circumference at the smaller end. By means of this the gases are compelled to change their direction on passing through the muffler, as they would not have to do if the holes were punched directly in the baffle-plates.

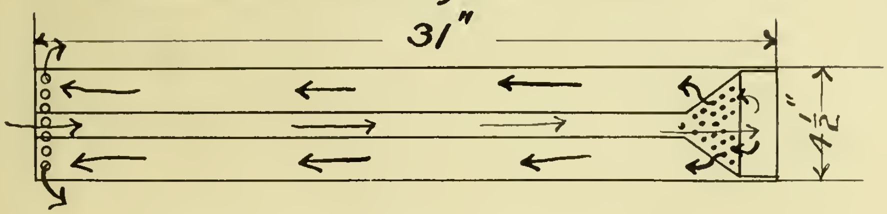
On the size of muffler inspected, inlet occurs at the center of the cylinder through a 2" pipe and the exhaust from the muffler is at the periphery at the end of the muffler.

The ratio of outlet to inlet area is .895.

The Oldsmobile Mufflers.



Oldsmobile Touring-Car Muffler



Oldsmobile Runabout Muffler

The muffler used on the Oldsmobile runabout is shown in the diagram above. Gas enters the central pipe at one end and flows through to the other end as indicated by the arrows. From there it passes through a cone pierced with 70 1/8" holes, and expands in the large chamber. Gas passes from this chamber to the air through 18 1/4" holes.

The muffler used on the touring-car is shown in the top figure. The gases enter a C. I. expansion chamber at the top and are deflected by the curved plate to the end of the chamber. The gases then force their way by the incoming gases and enter a 1 3/4" steel tube. This tube is pierced by 300 slots 2 1/2" long by 3/32" wide. The gas passes through these slots

into a cone shaped sheet-iron expansion chamber. This expansion chamber is divided into two sections by a baffle plate pierced with holes. The gases pass through these holes into the second section and from there into the tube slotted as in the first section and on into the air.

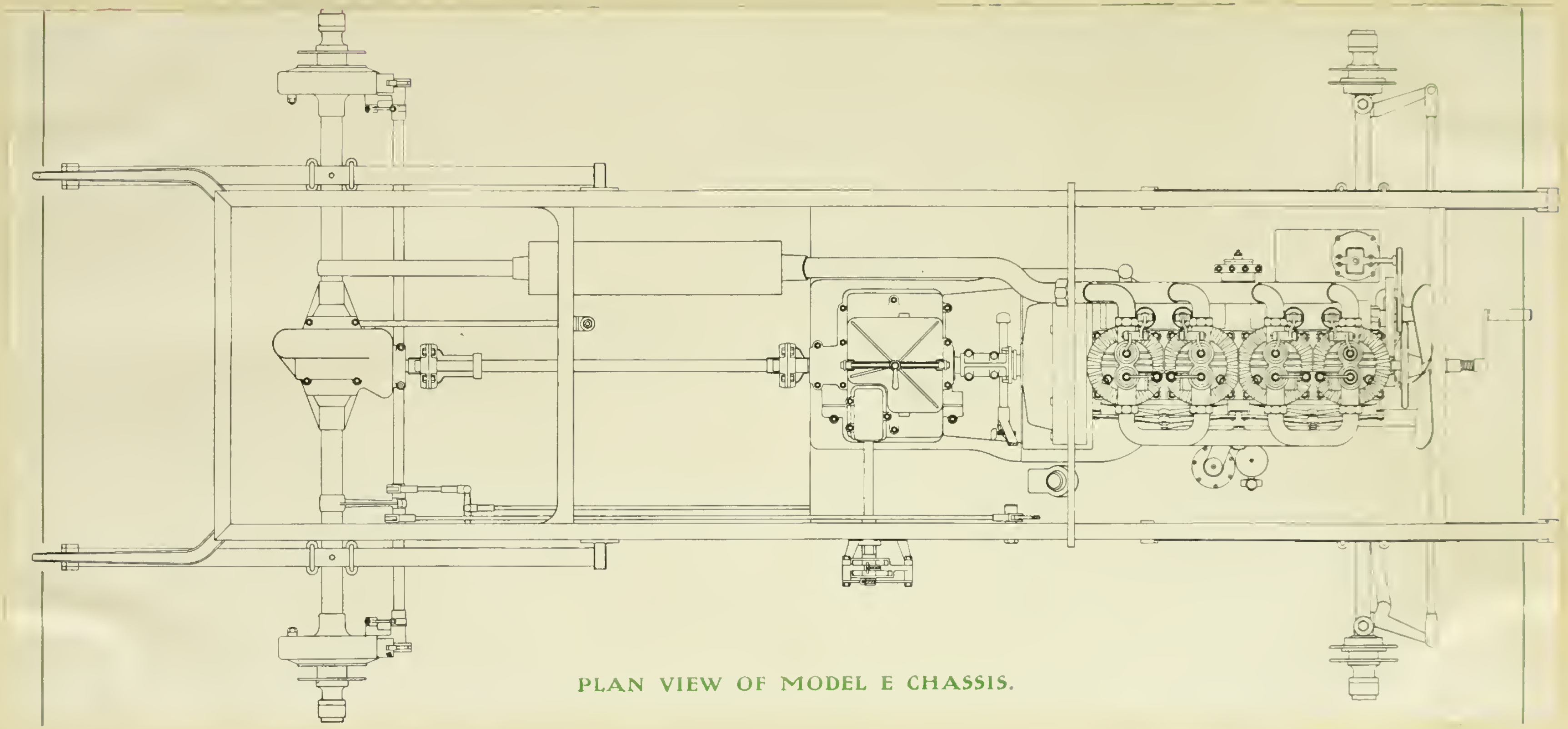
This muffler presents a large cooling surface,has no small holes that are liable to clog with soot, and provides a large volume for expansion. In a test made at the factory, this muffler gave 1# back-pressure at 1000 R. P. M. of the motor. The back-pressure was measured by means of a mercury column. This muffler embodied the most rational ideas of any mufflers examined.

The Weeber Muffler.

The Weeber muffler is a patented muffler of the form shown in the figure. The exhaust enters the muffler at the head, C. In this head are many small diverging tubes in which the gases expand. The gases then enter the converging tubes, B, which are set in the head, D.

The 7 1/2" x 13 1/2" Weeber muffler is used on all sizes of the Columbia car up to 50 horsepower. The inlet is through a 2" pipe and the outlet through a 1" pipe.

Ratio of outlet to inlet area is .256.



PLAN VIEW OF MODEL E CHASSIS.

THE CORBIN MUFFLER

The Corbin Muffler.

The muffler used on the Corbin automobile is of the concentric chamber type, the outer cylinder being 5" by 24". The inlet to the muffler is a 1" cast iron pipe and the exhaust from the muffler is through the same size of pipe.

If V is the volume of muffler in cubic inches,

v is the volume of cylinders in cubic inches,

R is the radiating surface of muffler in square inches,

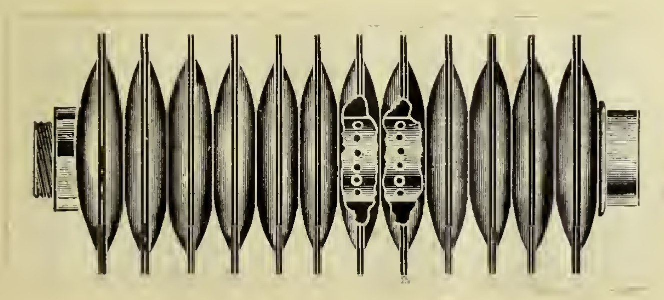
For the Corbin

$$\frac{V}{v} \text{ equals } 1.96$$

$$\frac{V}{R} \text{ equals } 1.25$$

On the preceding page is a cut of the muffler on the chassis of the Corbin car. This shows very well the position of the muffler in the average run of cars.

The "Yankee" Muffler.

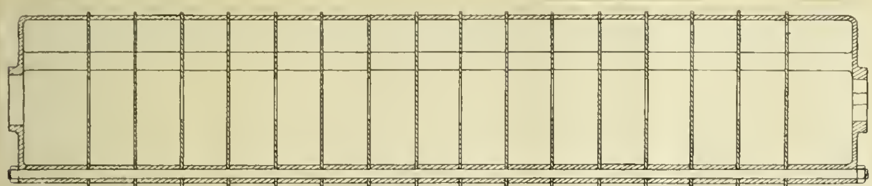


The "Yankee" muffler is composed of 24 opposed spring discs on the end of the exhaust pipe. The exhaust pipe is bored with several small holes so as to admit gas into the 12 chambers formed at the same time. Each pair of discs is practically a small radiator

and the volume of the gases is reduced by cooling owing to the great cooling surface presented. The gases escape from around the outer edges of these discs in a thin stream.

This equal distribution of the escaping gases over a long and narrow area eliminates to a large extent the explosive character of the exhaust. The discs, being light, free themselves of all soot and foreign matter, due to the force of the explosions.

The Pierce Muffler.



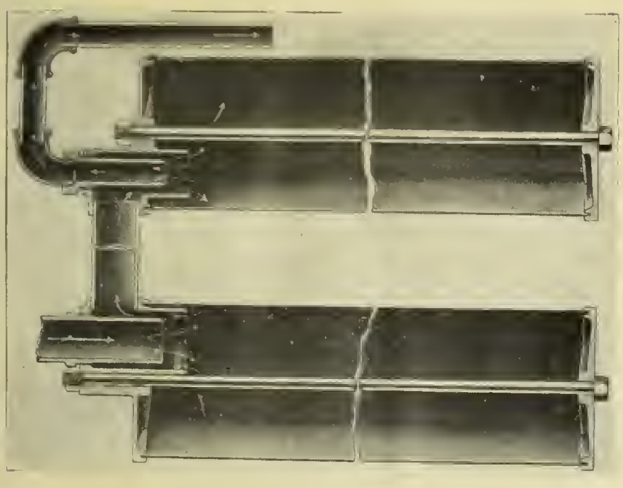
The Pierce muffler is a large expansion chamber, 5 5/8" x 30". This is divided into seventeen compartments by pierced sheet iron diaphragms. The separating diaphragms are of two sorts, one perforated with 3 circles of 9/32" holes, the aggregate small hole area equaling that of the 2" diameter openings with which the other sort of diaphragm is centrally pierced. These are placed alternately commencing with those having small holes at both ends. Thus the rush of the exhaust is diverted to the outside in the sucessive chambers.

The inlet to the muffler is through a 1 1/2" pipe. The outlet is a piece of 2" tubing screwed into the tapped head, bent at an angle of about 15 degrees downward, and terminating in an open end, the area being contracted by flattening the 2" tube

to an elongated opening 3/8" wide.

Ratio of outlet to inlet area is .32.

The Cadillac Muffler.



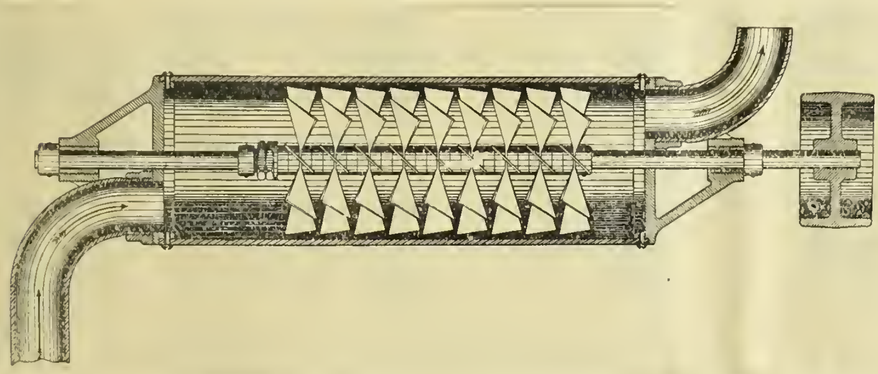
The Cadillac muffler as shown in the figure is used on the Cadillac four-cylinder car. It consists essentially of two sheet iron expansion chambers placed in series. These cylinders are 6" in diameter and 30" long, set parallel and lengthwise of the chassis, and are entirely open and unobstructed from end to end. The exhaust pipe from the motor enters the left hand muffler shell, in the middle and is free to shoot the whole length. The exit from the first muffler shell is an annular space surrounding the exhaust pipe entrance; this annular space is piped at right angles to the front end of the other muffler shell, which has the same arrangement as in the first shell. The exit is an annular space surrounding the second exhaust pipe, and leading to the open air.

The exhaust exit from the first cylinder is retarded by the opposing gases of the entrance exhaust on the annular exit chamber, and the exit from the second muffler shell to the open

air is similarly retarded. The muffler shells are not pierced and nothing passes through them. The open exit is of less area than the motor exhaust pipe, and the second exit area is still less.

On the Cadillac single cylinder car only one expansion chamber like the first chamber of the four-cylinder car muffler, is used.

The Davis Muffler.



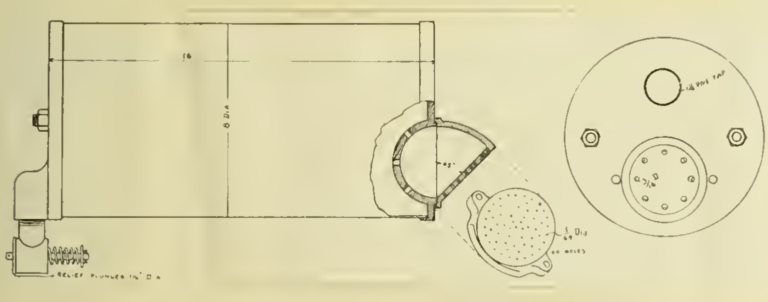
Something entirely different from the ordinary run of mufflers is shown in the accompanying cut. The exhaust from the engine passes into the cylinder through the inlet pipe and expands against the blades, absorbing the noise, while the revolution of these fans produces a suction from the exhaust valve, thus materially decreasing the back-pressure. The vanes are rotated by means of a sprocket and chain running to the engine.

There is no doubt that this arrangement would tend to decrease the back-pressure on the piston. If the power taken

off the engine to run the fans was not great, it is very likely that this power would be given back several times over by insuring a good clean mixture.

A 6 to 1 gear reduction is used on this ordinarily. If run at higher speed the back-pressure would be reduced but probably not sufficiently to make up for the extra power used to run the vanes at the higher speed.

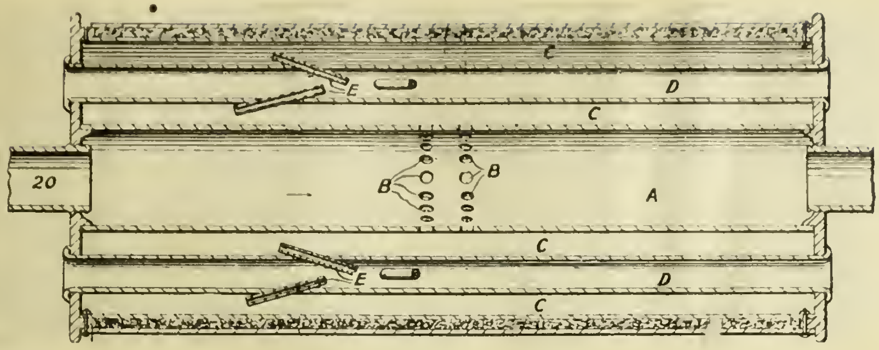
The Michigan Muffler.



The Michigan muffler is a simple expansion chamber, 8" x 15", weighing 50 pounds. The sheet steel shell is double with a thickness of asbestos between. The entire interior of the muffler is open and unobstructed; the exhaust enters near the top of one end and leaves through two circles of perforations, 8-3/16" holes, leading into an elbow having a closed outer end pierced with 64-3/32" holes. The cut out valve is retained by a coiled spring and acts as a relief valve in case of unusual muffler pressure.

Ratio of outlet to inlet area is .36.

The Bates Muffler.



This muffler is designed with a view to reducing the volume of the exhaust gases as much as possible by cooling before discharging them. The muffler is cylindrical in form and is placed lengthwise in the car, the left end of the cut being the front end of the muffler. The gases may enter at either or both ends, and a cut out may be placed at the unused end. The central chamber, which the gases enter first, is several times the volume of the engine cylinder and therefore gives the gases a chance to expand. The holes BB are likewise at least equal in total area to the cross-section of the exhaust pipe, and on passing through them the gases are still further expanded to the outer chamber, C. Through this chamber pass several flues, D, open at both ends so that the air can pass through freely. The exhaust gases enter these flues by the short pipes, EE, which are directed backward into the tubes so that the issuing gases assist the motion of the vehicle in drawing cool air through the flues.

The cooling and condensation of the gases take place

partly by convection and partly by the mixing of the air and gas in the latter. The muffler as shown is made with cast-iron heads and galvanized iron shells, and is surrounded by a jacket filled with asbestos to deaden the noises. This necessarily sacrifices a great deal of the cooling effect and the muffler would be much more efficient if the asbestos packing were left out entirely.

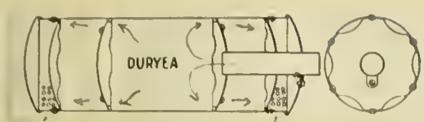
The Locomobile Muffler.

The Locomobile muffler is cylindrical in form, 7 1/2" in diameter by 23" long. The gases enter the muffler through 1 1/2" steel tubing. The muffler is divided into four chambers by baffle plates. The first baffle plate is pierced by 100 - 3/8" holes, the second and third baffles by 250 - 1/4" holes each. The gases pass through these chambers successively. The variation in area of the exhaust passage is shown in Curve 2 page 71 .

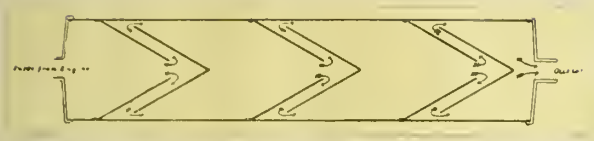
The outlet from the muffler is through a nozzle of steel tubing, running from 1 11/16" in diameter down to 1 1/4" at the end.

This contracting of the outlet area by a converging nozzle of steel tubing is a form of construction peculiar to all the foreign cars and to most of the high priced American cars. The claim is made that this converging nozzle of steel tubing gives a low roar instead of a sharp exhaust. In our tests with nozzles, our experience was just the reverse of this. The exhaust had a sharper sound and undoubtedly the nozzle increased the back-pressure.

The Duryea Mufflers.



1905 DURYEA


1906 DURYEA MUFFLER

The 1905 Duryea muffler is shown in the upper cut. It is an expansion chamber divided into five separate compartments by four spherical shaped baffle-plates. Gas enters through a pipe at the center of the muffler and expands in the central chamber. The gas then flows both ways from the center through the openings at the outer edge of the baffle plates into the succeeding chambers and similarly to the outermost chambers. From there it passes into the air through a series of holes. These holes become clogged very readily,so in the 1906 muffler this was the particular fault remedied.

The 1906 Duryea muffler is divided into chambers,as shown in the figure,by cone shaped baffle plates. These are not pierced by holes as in the ordinary construction, but a free exhaust area is offered to the gases. With this arrangement there is no possibility of the passages being clogged up by oil or soot.

The ratio of the muffler volume to that of the cylinders is 3.2, a good allowance for expansion. The casing is not asbestos lined and presents a good cooling surface to the air. The inlet of the muffler is through a 2" pipe and the outlet through a 1" pipe. Ratio of outlet to inlet area is .39.

The Burr Muffler.

page 50

The Burr muffler, as shown in Fig.1 consists of three concentric chambers clamped between two cast iron headers by four long bolts. Into these headers are screwed the 2" inlet and outlet pipes.

The two inner chambers have each one hundred 1/8" holes around their peripheries, but at opposite ends. A cap with four holes, each 3/4" square, around its periphery is interposed between one end of the two inner chambers and the outlet end of the muffler, thus allowing the gases to expand successively from the inner to the outer chamber before passing into the outlet pipe.

A cap is screwed over the outer end of the outlet pipe, and the gases escape to the air through one hundred and sixty two 1/8" holes extending around its periphery. The variation in the areas of the exhaust passages as the gases pass through the muffler is shown by Curve 3 , page 72. The variation in volume of the successive chambers through which the gases pass, is shown by Curve 4 , page 73.

Ratio of muffler volume to the volume of the Otto gas engine is 2.5.

Ratio of volume to radiating surface is 1.75.

Ratio of outlet to inlet is .59.

The Moline Muffler.

The Moline muffler is made up of three concentric sheet steel cylinders of 5, 6, and 7 inch diameters, as shown in Fig. 2 page 51.

The gas enters at one end through a 1 1/4" pipe and expands in the first cylinder. It then passes through 40 3/16" holes at the other end into the next outer chamber. The opposite end of this cylinder is pierced by 40 3/16" holes, through which the gas passes to the outer-most chamber. The gas escapes from this chamber through 26 3/16" holes, and then by a 3/4" pipe into the air.

The variation of the successive exhaust areas is shown by Curve 3, page 72.

The variation of the successive volumes is shown by Curve 4, page 73.

Ratio of the muffler volume to the volume of the Otto gas engine is 2.13.

Ratio of volume to radiating surface is 1.75.

Ratio of outlet to inlet area is .356.

Other Mufflers.

On pages 60 and 61 are given the data collected concerning all the other mufflers examined. This includes in most cases the size of muffler, general type, size of inlet and outlet, ratio of muffler to cylinder volume, ratio of the muffler volume to the radiating surface, and the ratio of outlet to inlet area.

PART 2

AUTOMOBILE MUFFLERS

INTRODUCTORY REMARKS

In the tests of mufflers described in this thesis, the effects of the muffler on brake horse power, back pressure on the engine, and the degree of noiselessness, were the main points of consideration.

It was the original intention to secure as many different kinds of mufflers as possible from the different manufacturers, but owing to untoward circumstances, we were unable to secure sufficient satisfactory types. As a result of this, the investigations were confined chiefly to two mufflers, one of which was kindly loaned to us by the E. W. Burr Machine Co., of Champaign, Illinois, the other by Root & Vandervoort Co., of Moline, Illinois.

To approach commercial conditions as nearly as possible we endeavored to use the two cylinder automobile engine made by Mr. Franklin in the University shops. After a number of tests it proved unreliable for our purpose; and it was decided to use the Otto ten horse power engine, in the M. E. laboratory of the University of Illinois.

AUTOMOBILE MUFFLERS

Tests of Automobile Mufflers appear to have been very scarce in the past. Practically the only data that could be obtained were those in regard to the Muffler contests held in 1903 and in 1905, under the auspices of the Automobile Club of France.

An effort was made to learn the actual conditions of the test; that is, the apparatus used and the manner of conducting the test, but little besides the actual results could be learned.

In the competitive test for mufflers held by the Automobile Club of France, the following items were, -

Factors in trial.

1. - Noiselessness
2. - Absence of Back-pressure
3. - Size and Weight
4. - Prevention of Smoke
5. - Simplicity and Cost of Manufacture

The data of these tests are given on page 62.

DESCRIPTION AND EXPLANATION OF METHODS OF OPERATION OF TESTING APPARATUS

The apparatus in general consisted of the following parts.

1. - The engine

2. - Device for measuring brake horse power

3. - The indicator and reducing rig

4. - Device for cooling the exhaust gases

5. - Apparatus for measuring the back-pressure

6. - Apparatus for obtaining temperature of gases before entering muffler

7. - Apparatus for determining the relative noiselessness of the muffler

8. - Device enabling one to readily cut out the muffler and exhaust directly into the atmosphere

The description of the two mufflers tested is given on pages 21 and 22.

DESCRIPTION OF APPARATUS

I. Engine.

The engine first used was of the two cylinder four cycle vertical type, constructed by Mr. H. B. Franklin, of the class of '06, in the shops of the University of Illinois. Owing to the type of engine used, it was impracticable to secure the indicated horse power of the engine, and it was left to the brake horse power, the real criterion in any case, to determine the power of the engine when exhausted through the muffler or directly into the air.

The normal rating of this engine was twelve horse power. Its R. P. M. varied from 400 to 700, depending on the load. The general arrangement of this engine with apparatus is shown in photograph on page 46 .

As this engine had no governor, the variation in power, due to the muffler being in or out of circuit, manifested itself in increase or decrease of R. P. M., rather than in change of load on the brake arm. With this engine it was found after several tests, that the maximum B. H. P. was decidedly variable. At times more power could be secured with the muffler in circuit, than was obtained when exhausting directly into the atmosphere. Again the speed would run down without any apparent reason, and in general proved so flighty and unreliable that it was thought better to secure some other engine in which the R. P. M. was fairly constant, and the load on the brake arm the variable factor.

With this end in view, it was decided to utilize the ten horse-power Otto gas engine. This engine was somewhat objectionable, in that it is a stationary engine rather than an automobile engine. Its normal speed, 300 R. P. M., is considerably under that used in automobile practice; and furthermore it is only a single cylinder engine. However, these conditions make the test on the mufflers a more severe one, in that a large amount of burnt gases is expelled into the muffler at intervals, rather than smaller charges at shorter intervals, as in automobile engines. This engine is shown by photograph on page 47.

Engine Data.

1. -	Name of Engine	Otto
2. -	Manufactured by	Otto Gas Engine Works, Philadelphia, Pa.
3. -	Number of Cycles	Four
4. -	Kind of Fuel	Gasoline
5. -	Rated Horse Power	10 H. P.
6. -	Number of Cylinders	One
7. -	Bore of Cylinder	5 3/4"
8. -	Stroke of Piston	12 1/2"
9. -	Volume of cylinder	324 cu. in.
10 -	Clearance	107 cu. in.
11.-	Diameter of Flywheel	4' 8"
12 -	Rated Revolutions per Minute	300 R. P. M.
13 -	Governor	Hit or Miss
14 -	Ignition	Electric Contact
15 -	Kind of Valves	Poppet

2. Device for measuring the B. H. P.

The B. H. P. was obtained by means of a Prony brake. This brake was of very good design and gave no trouble at any time during the test. The construction of this brake is shown in Fig. 4 page 53.

Length of brake arm is 62 1/2".

The load on the brake arm was taken by a carefully calibrated Fairbanks platform scale as shown in photograph on page 48.

The R. P. M. was obtained by means of an ordinary speedometer used in conjunction with a stop watch.

3. The indicator and reducing rig.

An ordinary Crosby steam and gas engine indicator was used in taking pumping diagrams. Pumping diagrams are indicator cards taken with a very low spring, so that the comparatively small forces due to suction and exhaust may be clearly shown. In an ordinary card taken with a 240# spring, a back pressure as high as 10# will apparently coincide with the atmospheric line. A 10# spring with a stop to prevent the limit of the spring being exceeded was used in the indicator.

The reducing rig used was one already on the engine. Considerable difficulty was experienced with this rig becoming loose and shaky, and varying the length of the cards. After tightening and adjusting the various parts, it worked very well and little trouble was experienced afterwards. The reducing rig is shown in Fig. 5 page 54.

4. Device for cooling the exhaust gases.

Cooling the exhaust gases reduces both the pressure and the volume. Thus a muffler which allows of sufficient cooling, may have less back pressure, and a greater degree of noiselessness than one with much greater expansion which does not cool the gases.

With a view to determine just what effect cooling had on the back pressure and the noise of the muffler, a cooler was constructed as shown in Fig. 6 page 55.

This is essentially a waterjacket placed on the exhaust pipe, leading from the engine to the muffler. Water was supplied to the cooler from the mains, and it was thought that by varying the amount of cooling water flowing through, the temperature of the exhaust gases could be correspondingly lowered.

On testing, the effect of the cooler could not be detected. That this failed to cool the gases was evidently due to the high velocity of the gases through the exhaust pipe. No tests were taken to determine theeffect of the cooling, as it was so slight in any case that the results would not be materially affected by it.

The arrangement of the piping to the cooler is shown in the piping diagram, Fig. 3 on page 52, and in the photograph on page 49.

5. Apparatus for measuring the back pressure.

Notwithstanding the fact that the B. H. P. would determine the loss of power due to the muffler, it was desired to ascertain the backpressure due to the muffler in pounds per square inch and obtain if possible the relation between loss of power and back-pressure in pounds per square inch.

The first method tried was this.

A 1/2" hole was tapped in the pipe, just in front of the muffler, in which was placed an indicator cock. A gas engine indicator with the lightest spring available, a 16# spring, was placed on the cock. It was thought that by turning the indicator drum a continuous record of the back-pressure would be traced on the card. On actual trial, however, the back-pressure was not sufficient to even move the indicator piston. As no lighter springs were at hand, this method was clearly out of the question.

A low pressure steam radiator gauge was next placed on the exhaust. This showed that there was some back-pressure, as the pointer moved with every explosion of the engine, and that the indicator was not of sufficient delicacy to register it.

Finally a U tube partly filled with mercury, was connected to the exhaust. This was found to be quite delicate and was used throughout in determining relative back pressure. The back-pressure measured by the mercury column evidently gives some rough average of the back pressure during the exhaust.

By taking a pumping diagram, from the engine, the exact back-pressure due to the character of the exhaust outlet is

clearly indicated for every point of the stroke. The average back-pressure by this method, is obtained by determining the mean pressure during the exhaust stroke.

Back-pressure was obtained by both methods until the stop on the indicator was crushed by an extra heavy explosion, and owing to the lack of time it was not repaired again for use. The mercury column alone was used in determining the back-pressure after this. Manometer is shown in Fig. 7, page 56.

6. Apparatus for obtaining temperature before entering muffler.

In order to obtain the temperature of the exhaust gases entering the muffler, and to determine the effect of the cooler, a stuffing box with valve, was put on the exhaust pipe in front of the muffler. A 1000 degree mercury thermometer was used.

This arrangement is shown in the photograph on page 49.

7. Apparatus for determining the relative noiselessness of the muffler.

In attempting to devise any means for measuring the intensity of the sound created by the gases issuing from the muffler, the difficulty of the undertaking became evident, also that in the end judgment must be made by means of the ear alone.

The device shown in Fig. 8 on page 57 was designed and constructed in the hope that it would measure the noise. This is made up of -

1. - A micrometer screw
2. - A diaphragm
3. - An electrical indicating apparatus

It was thought that the amplitude of the vibrations of the diaphragm would be proportional to the intensity of the sound. A circuit was formed in which the diaphragm was on one side and the screw of the micrometer on the other. When the point of the screw touched the diaphragm, the fact was indicated by a galvanometer placed in the circuit. The point of the screw could be advanced as desired until the contact was secured, and the distance that the diaphragm moved from its zero position determined the intensity of the sound.

When tested the device seemed to detect no difference between the intensity of different sounds. This was due undoubtedly to the small amplitude of the diaphragm. After considerable reading on the matter it became very evident that the ear was the only available means of measuring the sound.

The piping is so arranged that two mufflers may be connected at the same time and the gases sent through either one or both, thus two mufflers of nearly the same degree of noiselessness can be put on at the same time. An observer is stationed at a considerable distance from the engine and out of sight of the mufflers. The two mufflers are then cut in, alternately, and the quieter one selected by number, the observer being unaware of the order of numbering. Thus any prejudices an observer might have either for or against a special muffler would have no effect on the results.

8. Device for cutting out muffler.

This arrangement is shown by the photograph on page 49.

The exhaust is run into a T and two parallel passages made for the gases. Both branches are provided with a 2" quick-opening valve. The muffler may be placed on either branch and the different conditions desired are obtained by manipulating the quick-opening valves.

EXPLANATION OF METHODS OF CALCULATING RESULTS

B. H. P.

Where

L equals load on brake-arm in pounds.

r equals length of brake-arm in inches

n equals R. P. M.

$$\text{B. H. P. equals } \frac{2\pi rn \times L}{12 \times 33000}$$

$$\text{Loss in \% equals } \frac{\text{Loss in B. H. P.}}{\text{B. H. P. without muffler}}$$?

$$\text{B. H. P. per explosion equals } \frac{\text{B. H. P.}}{\text{No. of explosions}}$$

$$\text{Loss in \% equals } \frac{\text{Loss in B. H. P. per explosion}}{\text{B. H. P. per explosion without muffler}}$$

Back-pressure.

From manometer

$$\text{B.P. in lbs per sq.in. equals } \frac{\text{Deflection of mercury col. in inches}}{2.04}$$

From pumping diagram

In determining the back-pressure from the pumping diagram the area under the exhaust line is determined by means of a planimeter. The area divided by the length of card gives the mean height of ordinate. This ordinate multiplied by the scale of the spring used in taking the diagram gives the average back-pressure in pounds per square inch.

LIST OF TESTS

Test No. 1

Purpose of test.

To determine back-pressure and loss of power due to Burr muffler.

Manner of conducting test.

The B. H. P. was first determined by obtaining the load on the brake-arm and the R. P. M. The muffler was then put in circuit and the load and R. P. M. determined under these conditions.

Back-pressure was measured by a manometer attached to the exhaust pipe in front of the muffler. The manometer is shown in Fig. 7, page 56..

Result of test.

As this engine is equipped with a hit or miss governor, this method gave us no results whatever as may be seen by consulting the data and result sheet of this test on page 63 . Instead of load on brake-arm,or the R. P. M. being reduced by putting the muffler in circuit, more explosions were obtained and the load and speed were both kept up at all powers under 9 H. P., the limit of the engine.

Test No. 2

Purpose of test.

To determine the back-pressure and loss of power due to Burr muffler.

Manner of conducting test.

Obviously the only means of determining the loss of power due to muffler, and still utilizing the Otto engine, was to determine the variation in the number of explosions needed to keep the engine at its normal speed under load both with and without muffler.

In this test the explosions per minute were determined by counting R. P. M. and load on brake-arm were taken to determine the brake horse power developed at the time the explosions were counted. Back-pressure was measured by the manometer.

The muffler was put on one side of the testing apparatus and the other left open. A minute test was then run with the muffler in circuit. By means of the valves, the muffler was cut out and the test repeated with the gases exhausted directly into the air.

Result of test.

Data and results are given on page 64 .

The back-pressure as determined by the manometer was about 1.4# per square inch. The average loss of power was 3.2%. This value is undoubtedly low for the loss of power. 6% would probably come closer to the actual loss.

Test No. 3

Purpose of test.

To determine the back-pressure and loss of power due to Moline muffler.

Manner of conducting test.

This test was conducted similarly to Test No. 2.

Result of test.

Data and results of this test are given on page 65 .

The average back-pressure as determined by the manometer was 3.4# per square inch. The average loss in power due to the muffler was 10.1%. The actual loss was probably somewhat more than this.

Test No. 4

Purpose of test.

To determine back-pressure and loss of power, when an expansion chamber is used with

1. - Unobstructed outlet
2. - Small holes as outlet
3. - Converging nozzle as outlet.

Manner of conducting test.

In this test the two concentric sheet-iron cylinders were taken out of the Burr muffler, leaving nothing but the shell and the outlet pipe attached to the head. The exhaust gas now enters the shell, which acts as a mere expansion chamber, and passes out through the 2" pipe.

This test was conducted similarly to Test No. 2, with

1. - Unobstructed outlet.

   The outlet pipe was left perfectly free and open.

2. - Small holes as outlet.

   The end of the outlet pipe was closed by means of a plug and the gases passed from the expansion chamber to the open air, through 162 - 1/8" holes at the circumference of the outlet pipe.

3. -- Converging nozzle at outlet.

The plug was taken from the outlet pipe and the converging nozzle shown in Fig. 9, page 56, was placed on the end. With this arrangement the gases passed, part through the small holes and part through the nozzle.

Result of test.

The data and results of this test are given on page 66.

1. -- Unobstructed outlet.

The average back-pressure was .5# per square inch and the average loss of power, 2%.

2. -- Small holes as outlet.

The average back-pressure was .86# per square inch, and the average loss of power was 2.3%.

3. -- Converging nozzle as outlet.

The average back-pressure was .53# per square inch while the average loss of power was 7. 06%. The value for average loss of power is much too high, as the back-pressure was low in this case.

Test No. 5

Purpose of test.

The purpose of this test was to determine the effect of interposing between the cylinder and the muffler, a long length of pipe.

Manner of conducting test.

A 20' length of 2" pipe was attached to the exhaust at the cut out. The gases were then sent through this pipe and the back-pressures, with pipe unobstructed, pipe with nozzle, pipe with Burr shell and plug, pipe with Burr shell unobstructed, pipe with Moline muffler, and pipe with the Moline muffler with a 3/4" outlet pipe, were taken with the manometer.

Result of test.

The data and result of this test are given on page 67. The interpolation of this pipe appeared to increase the back-pressure in most of the cases, while in others the back-pressure seemed to be slightly reduced.

Test No. 6

Purpose of test.

This test was taken to determine the variation of back-pressure with a load on the brake arm, when exhausting into the

1. - Moline muffler.
2. - Burr muffler.
3. - Both mufflers.
4. - Open air.

Manner of conducting test.

Back-pressure was determined by two different methods.

(1) - By means of manometer.

(2) By taking pumping diagrams and determining the M. E. P. under the exhaust line.

Back-pressure was determined by these two methods at the following brake-arm loads, 0, 6 2/3, 13 1/3,20, and 26 2/3 pounds. When the engine is up to speed this corresponds to 0, 2, 4, 6, and 8 horse power.

Result of test.

The data and results of this test are given on page 68. The results as shown by curves, are given on page [illegible]4. The back-pressure by the two methods does not agree very closely as may be seen from the curves, yet they appear to bear some relation to each other. There seems to be no well defined load at which the back-pressure is either a minimum or a maximum.

1. - Moline muffler.

This muffler had by far the highest back-pressure. The average of the pumping diagram values being 6.15# per square inch, while the average of the manometer values was 4.3#.

2. -- Burr muffler.

The Burr muffler gave the next highest values 2.2# per square inch from the pumping diagrams, and 1.6# from the manometer.

3. - Both mufflers.

Both mufflers together, as might be expected, gave a lower back-pressure than either separately, 1.27# per square inch and 1.03# from the manometer.

4. - Open air.

When exhausting directly into the air, the back-pressure as determined by the pumping diagrams, was .65# per square inch, and by the manometer, .52#.

Sample pumping diagrams for each of these cases are shown on pages 58 and 59.

Test No. 7

Purpose of test.

To obtain the relative degree of noiselessness of the different mufflers tested.

Manner of conducting test.

The test was conducted as described on page 32 , the ear being the judge of the degree of noiselessness.

Result of test.

Due to the fact the exhausts from the different mufflers were ordinarily of a totally different character, it was deemed unfair to some of the mufflers, to attempt assigning arbitrary values as their relative degree of noiselessness.

The exhaust from the Moline muffler with a 3/4" pipe outlet was very quiet considering the engine it was on, giving only a slight blowing sound.

The Burr muffler was of about the same degree of noiselessness as the Moline. The exhaust was slightly explosive, differing materially in nature from that of the Moline.

The exhaust from the Burr shell with plug was rather heavy and explosive in character, while that from the Moline muffler without the 3/4" pipe outlet was a sharp blowing sound which carried much farther than the heavier one.

The exhaust from the Burr shell unobstructed gave a heavier sound than with the plug, but was still considerably quieter than the open exhaust.

The exhaust from the Burr shell with nozzle was a very sharp blowing sound. The muffler seemed quieter without the nozzle than with it.

When the twenty foot length of pipe was interposed between the engine and the muffler, the sound of the exhaust was sharp and snappy in character.

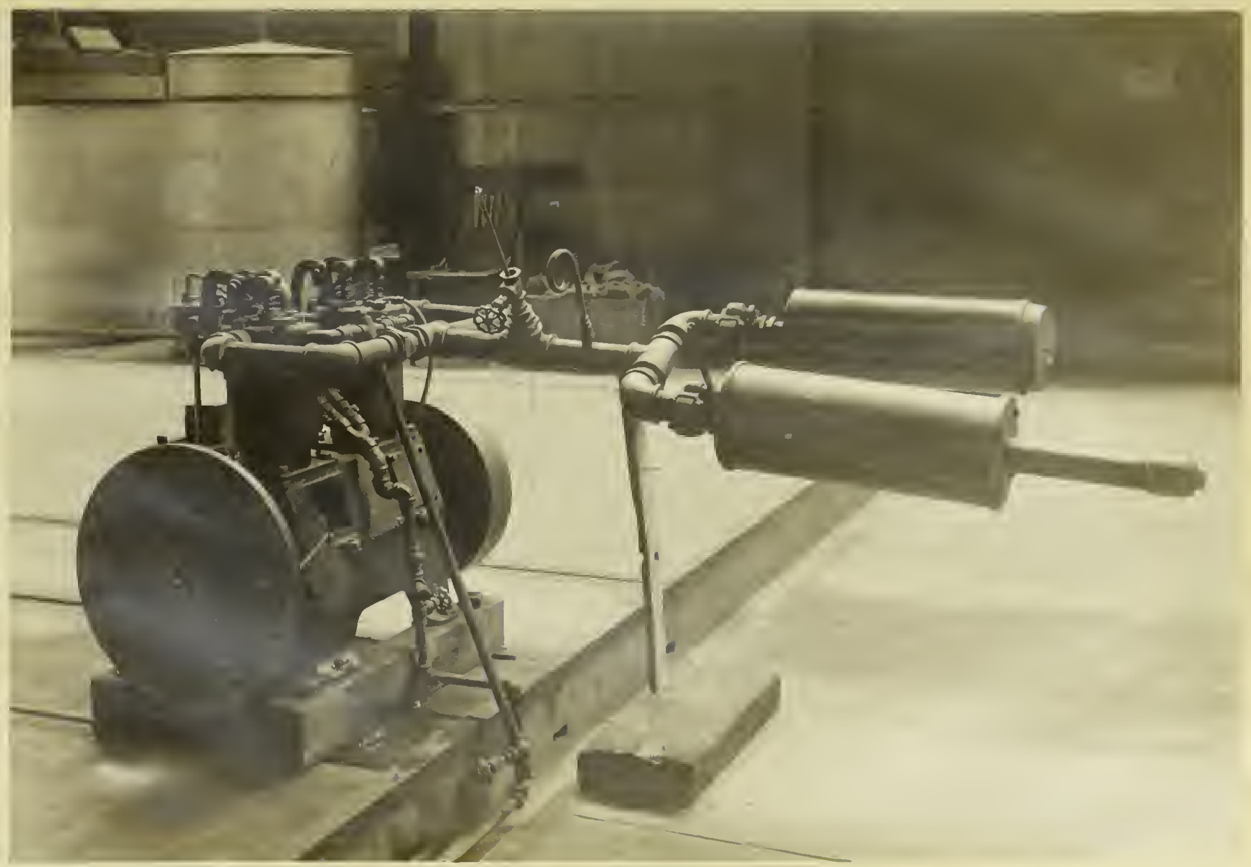
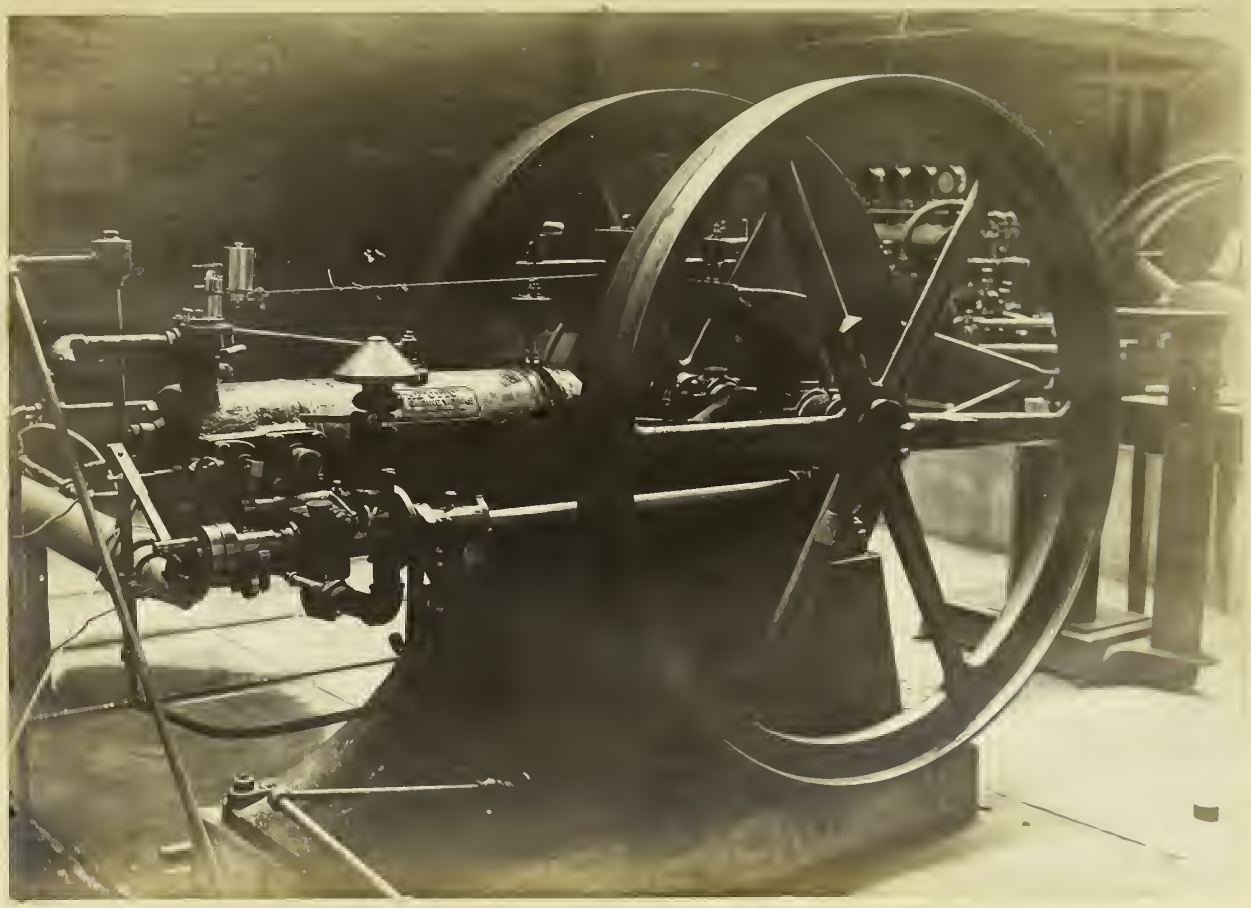
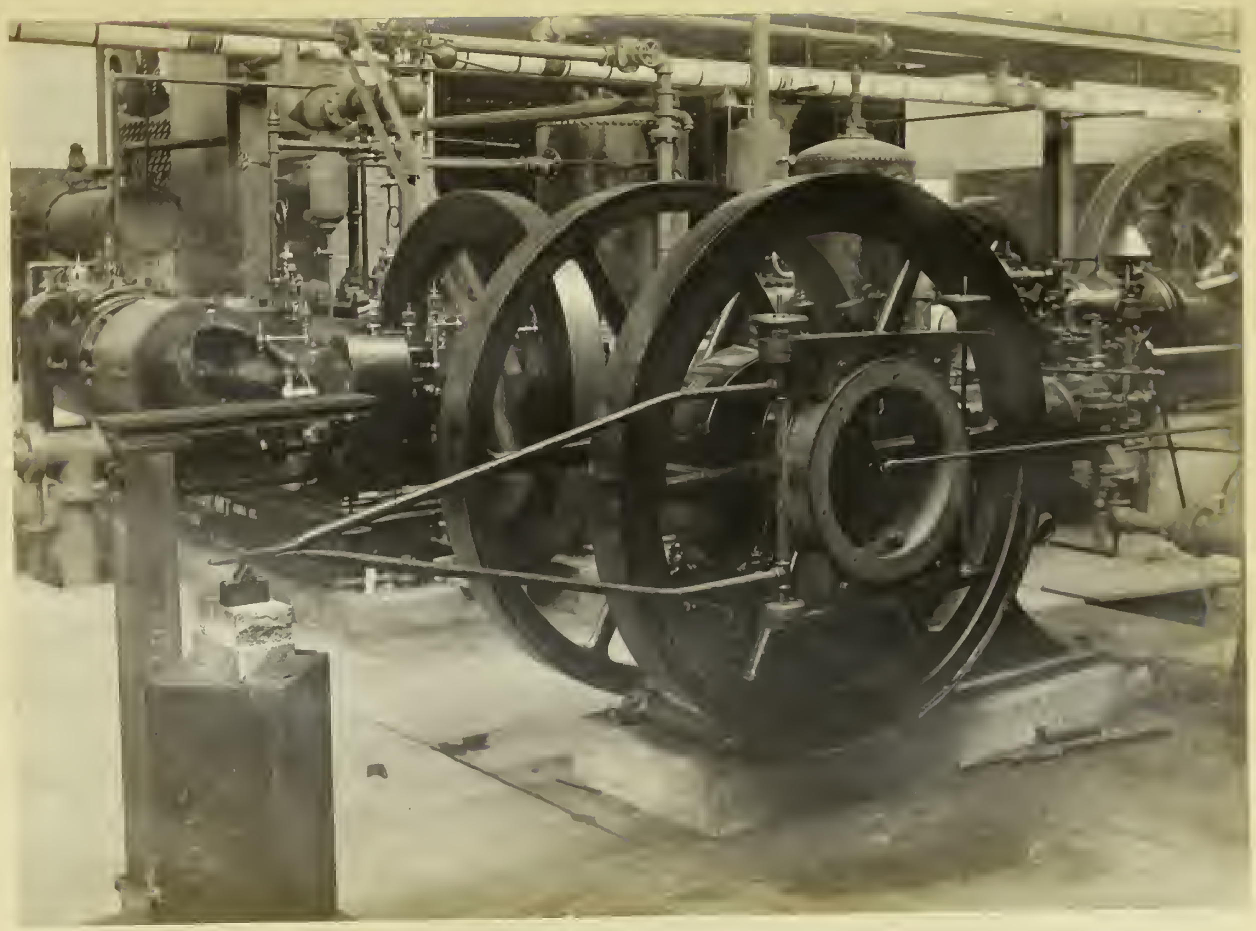


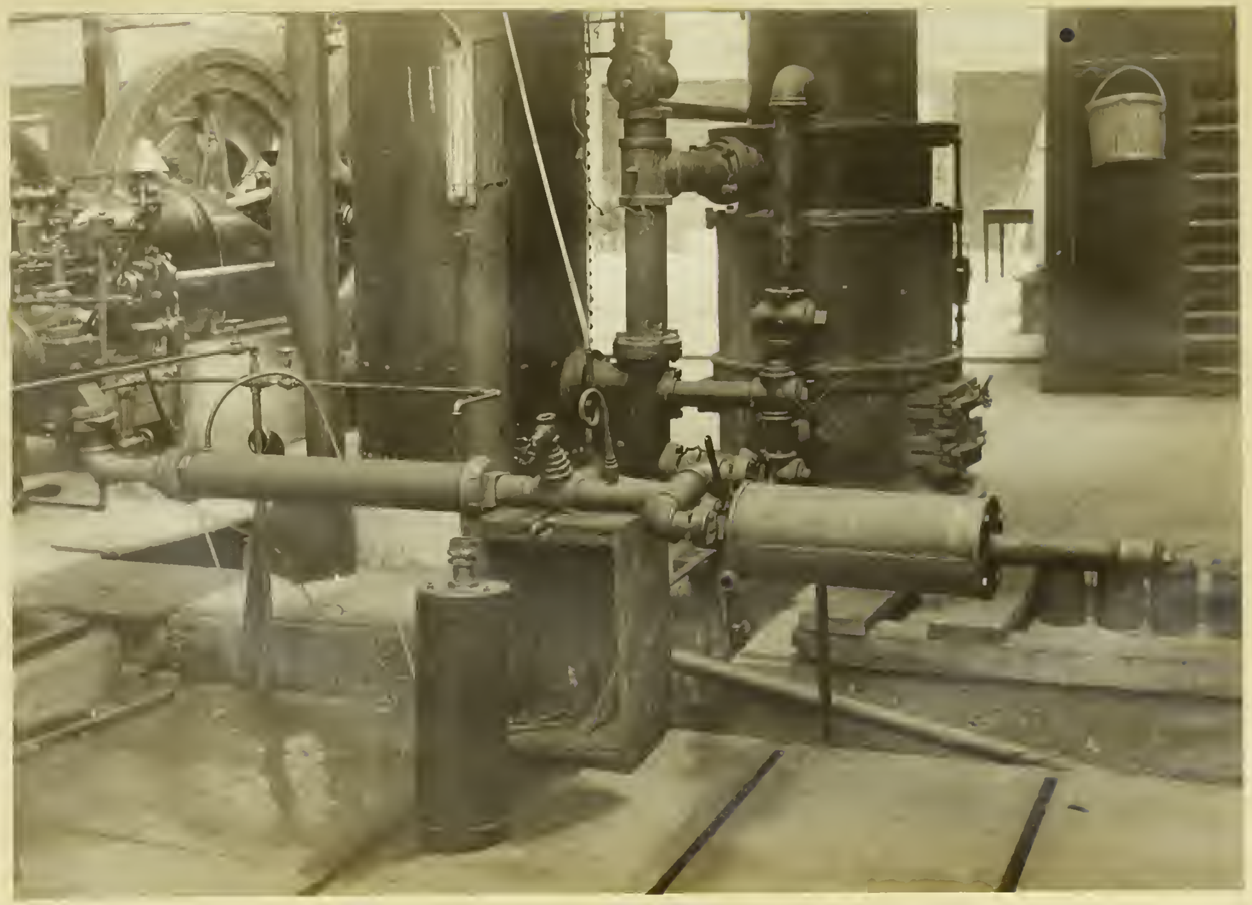
PHOTO SHOWING FRANKLIN ENGINE



PHOTOGRAPH SHOWING 10 H. P. OTTO GAS ENGINE



PHOTOGRAPH SHOWING PRONY BRAKE IN POSITION



PHOTOGRAPH SHOWING GENERAL ARRANGEMENT

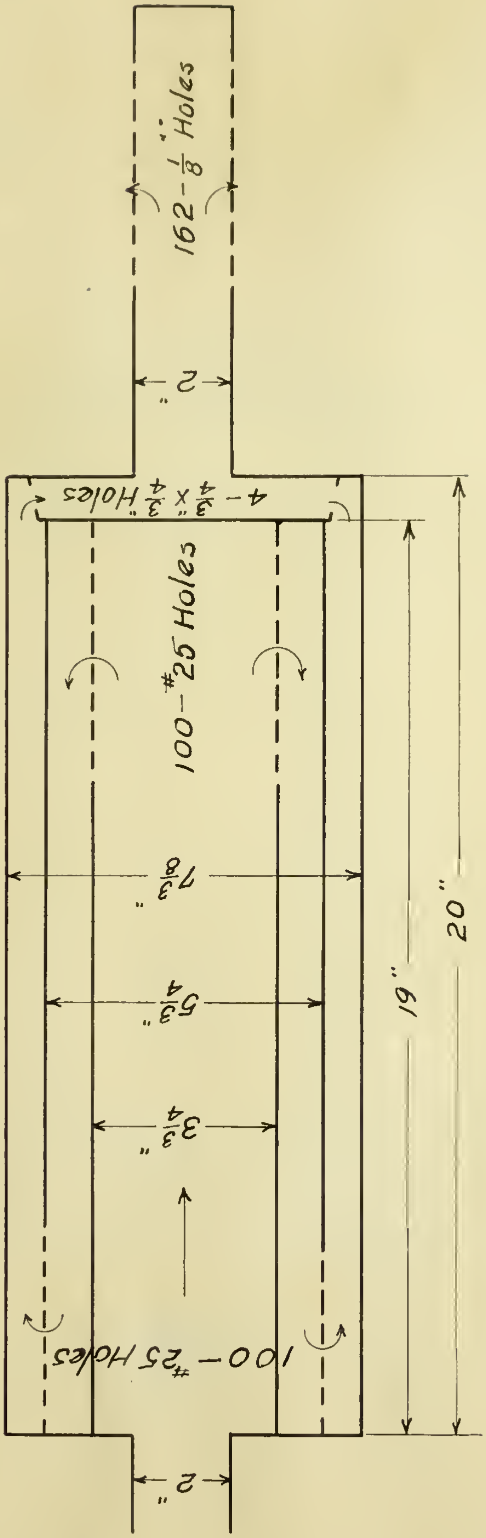


Fig. 1
BURR MUFFLER

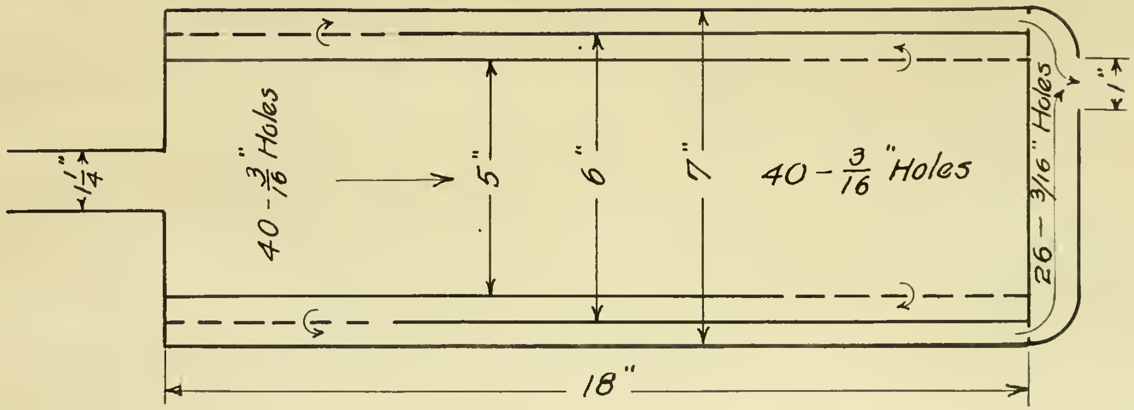
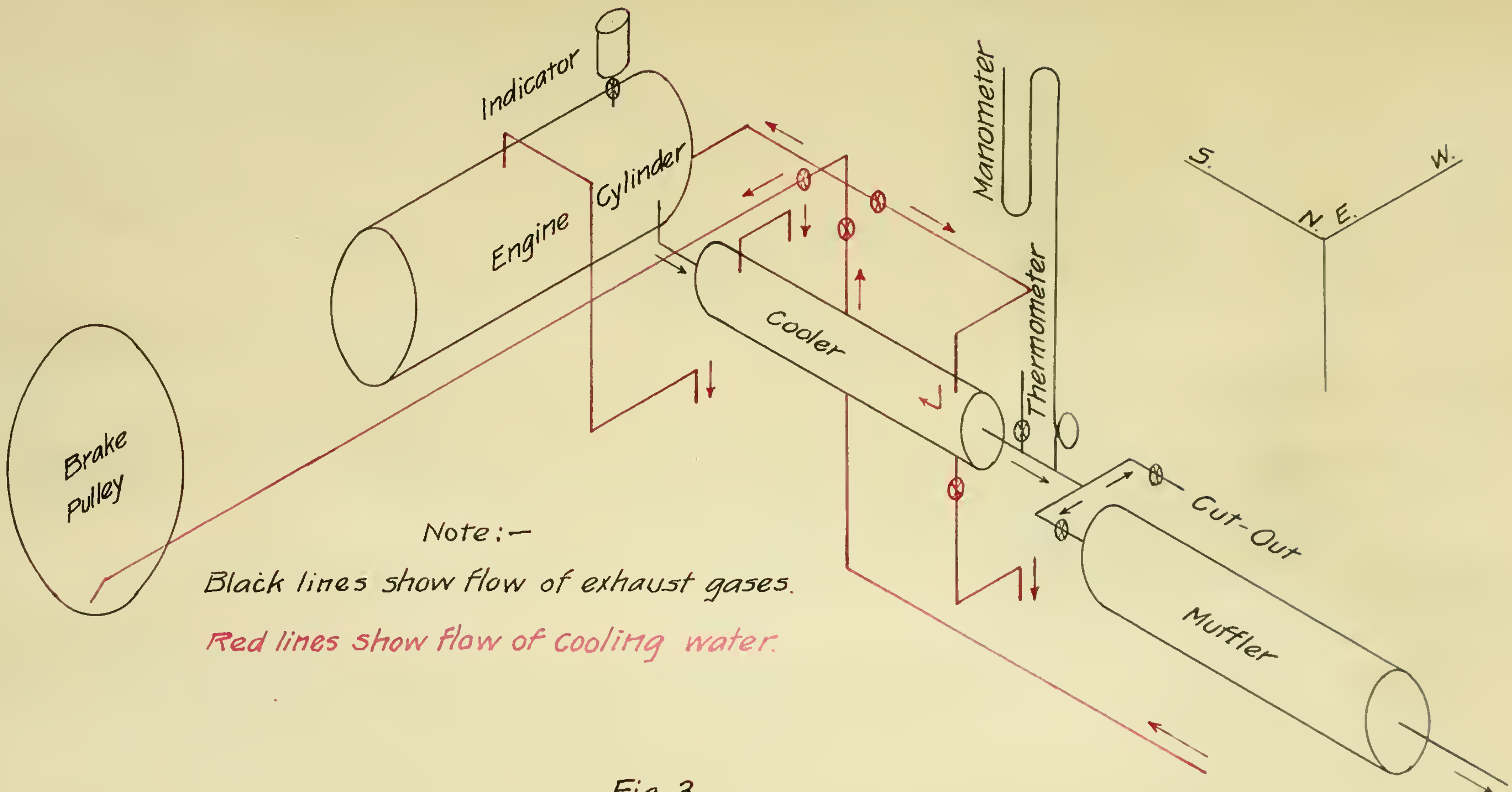


Fig. 2

MOLINE MUFFLER



Note:—

Black lines show flow of exhaust gases.

Red lines show flow of cooling water.

Fig. 3

DIAGRAM OF PIPING

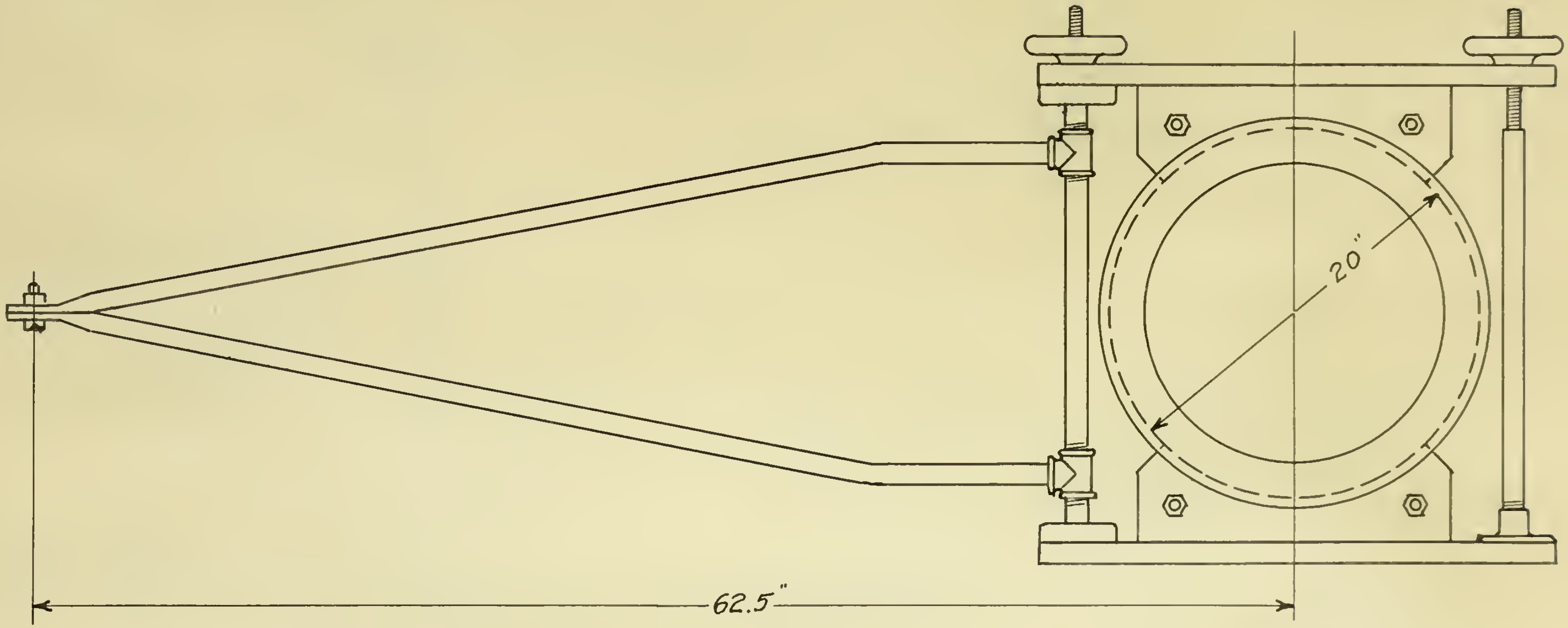


Fig. 4

PRONY BRAKE

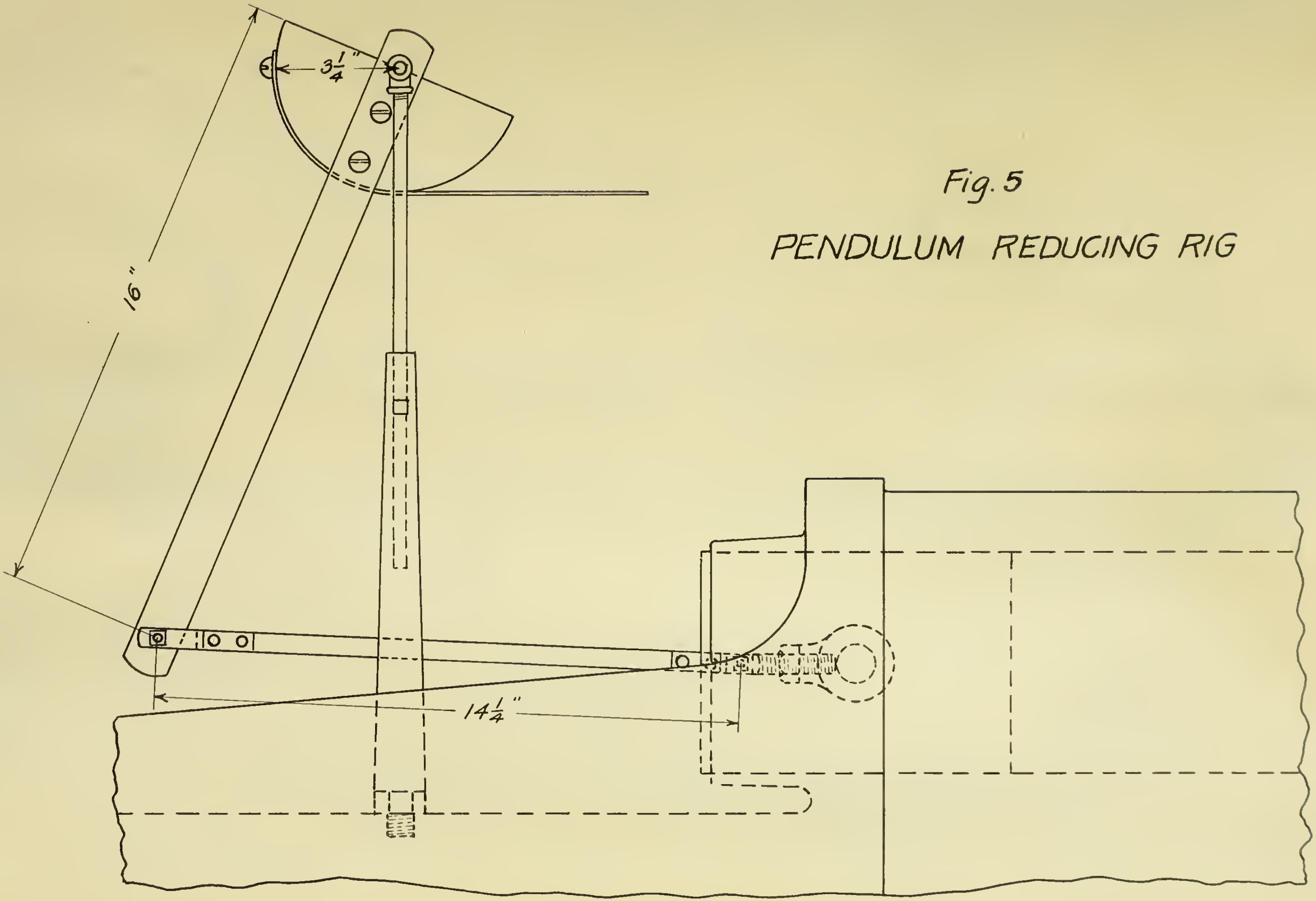


Fig. 5

PENDULUM REDUCING RIG

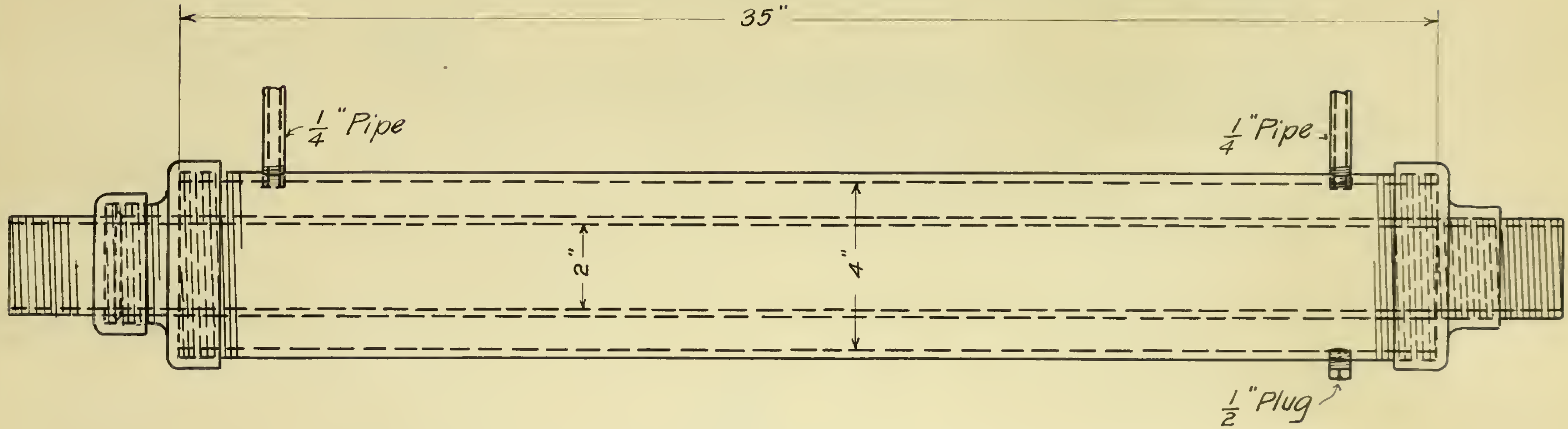


Fig. 6

APPARATUS FOR COOLING EXHAUST GASES

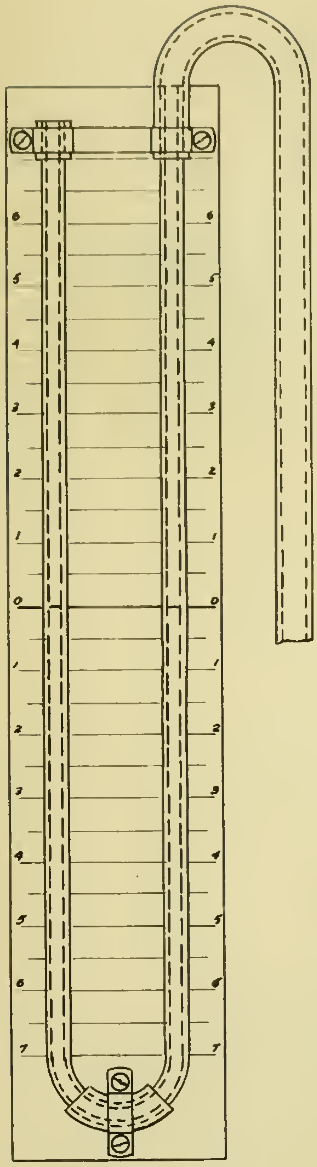


Fig. 7

MANOMETER

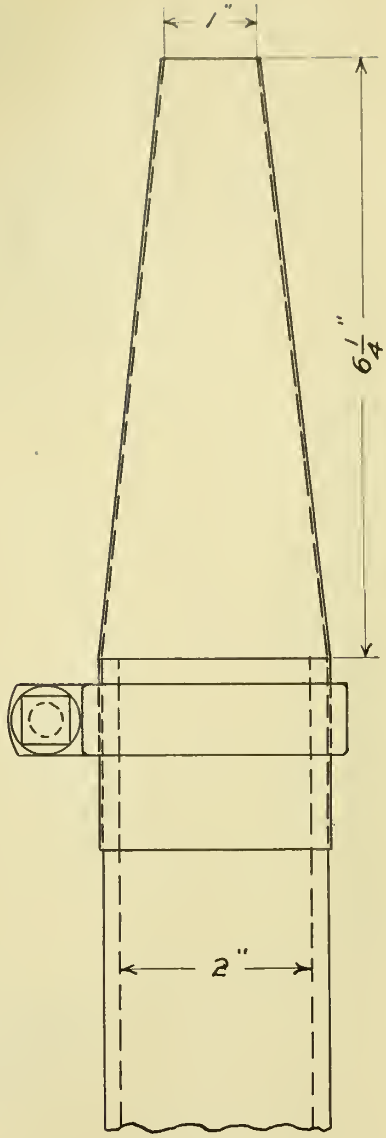


Fig. 9

NOZZLE

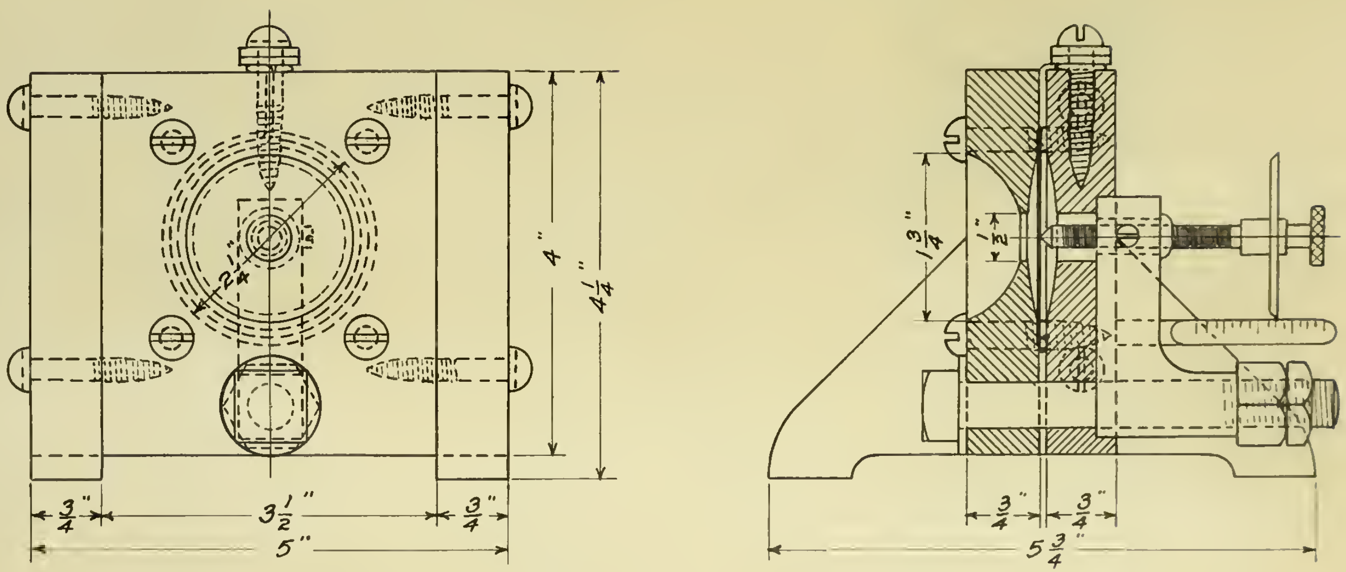
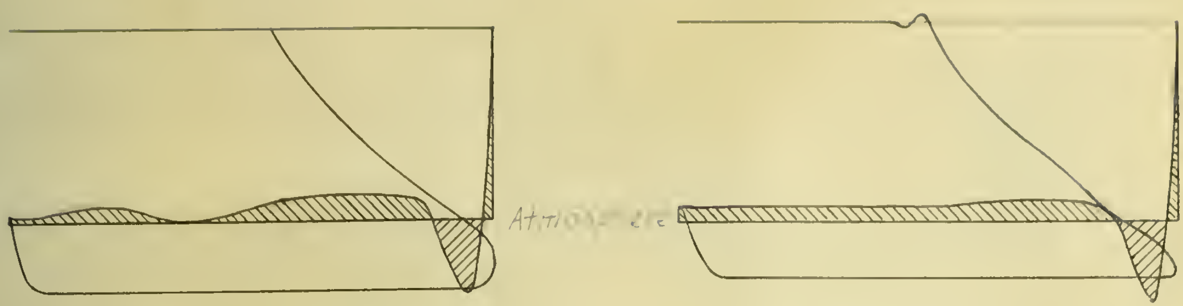


Fig. 8

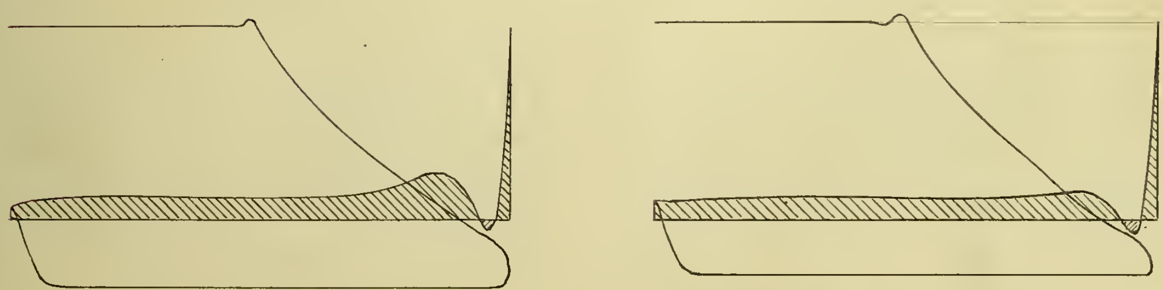
APPARATUS FOR RECORDING NOISE



No Load 0.7 Lb. B.P. 8.3 B.H.P. 0.7 Lb. B.P.
312 R.P.M. 314 R.P.M.

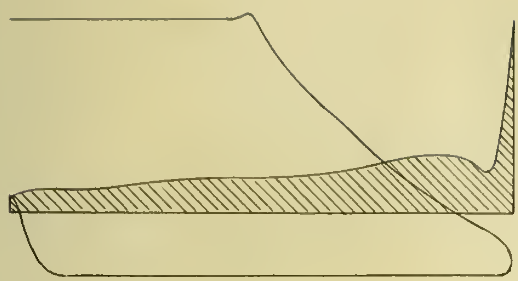
PUMPING DIAGRAMS WITHOUT MUFFLER

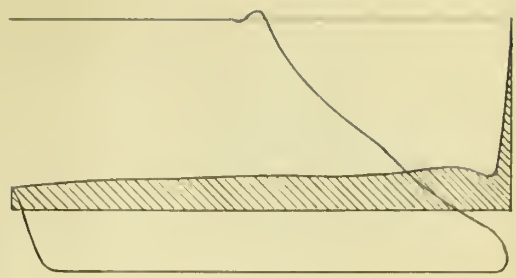
13# Spring.



No Load 1.4 Lbs. B.P. 8.3 B.H.P. 1.3 Lbs. B.P.
314 R.P.M. 314 R.P.M.

PUMPING DIAGRAMS WITH BOTH MUFFLERS





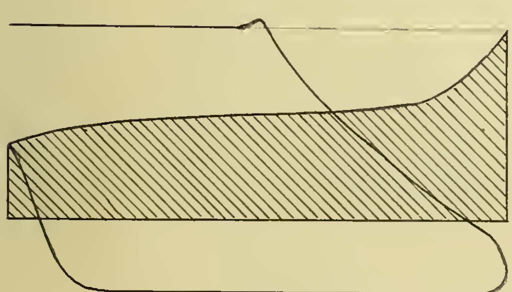
No Load
313 R.P.M.

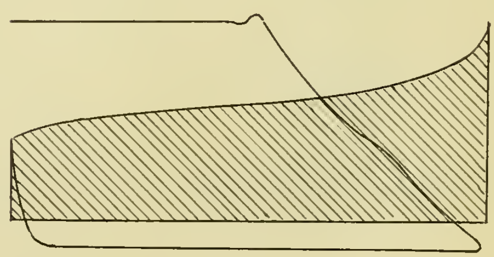
2.1 Lbs. B.P.

8.3 B.H.P.
314 R.P.M.

1.9 Lbs. B.P.

PUMPING DIAGRAMS WITH BURR MUFFLER
10# Spring





No Load
316 R.P.M.

5.8 Lbs. B.P.

8.3 B.H.P.
313 R.P.M.

6.0 Lbs. B.P.

PUMPING DIAGRAMS WITH MOLINE MUFFLER.
10# Spring

SUMMARY of DATA on MUFFLERS

Muffler						Piping		Motor		Ratios			Remarks
Kind	Type	Width	Length	R, rad. Sur. in □"	V, vol. in cu. in	Inlet	Outlet	Type	Total Vol., v	$\frac{V}{v}$	$\frac{V}{R}$	$\frac{\text{Outlet}}{\text{Inlet}}$	
Apperson	Tubes & Baffles	6"	18"	346	530	$1\frac{1}{2}$" I	2" I	4 cyl.	495	1.07	1.53	1.78	
Autocar	Ejector	6"	25"	481	737	$1\frac{1}{2}$" I	$1\frac{1}{4}$" S	4 cyl.	180	4.09	1.53	.70	
Hush	Baffle	6"	24"	462	708	2" I	Ring	—	—	—	1.53		
Buick	Concentric	$6\frac{1}{2}$"	28"	572	928	$1\frac{1}{4}$" S	36 – $\frac{3}{8}$ Holes	2 cyl. opposed			1.62	.81	
Cadillac	Opposed	6"	34"	654	1000	$1\frac{1}{4}$" I		1 cyl.	98	10.20	1.53		
Corbin	Concentric	5"	24"	377	471	$1\frac{1}{2}$" I	$1\frac{1}{4}$"	4 cyl.	241	1.96	1.25	.70	
Columbia	Tubes	$7\frac{1}{2}$"	$13\frac{1}{2}$"	318	596	2" I	1" I	4 cyl.	300	1.99	1.87	.25	
Darracq	Baffle	$5\frac{1}{2}$"	30"	518	713	$1\frac{1}{2}$" S	$1\frac{1}{2}$" S	4 cyl.	232	3.07	1.37	1.00	
Dolson		7"	31"	682	1193	2" I	$1\frac{3}{16}$" S	4 cyl.	992	3.05	1.75	.35	
Duryea	Conical Baffles	$5\frac{1}{2}$"	$28\frac{1}{2}$"	492	677	$1\frac{1}{2}$" I	$\frac{7}{8}$" S	4 cyl.	212	3.20	1.38	.34	
Ford	Concentric	6"	17"	327	501	$1\frac{1}{4}$" I	$1\frac{1}{4}$"	4 cyl.	284	1.76	1.53	1.00	
Franklin	Concentric	6"	20"	385	590		$1\frac{3}{8}$" S	4 cyl.	108	5.46	1.53		
Locomobile	Concentric	$7\frac{1}{2}$"	23"	542	1015	$1\frac{1}{2}$" S		4 cyl.	360	2.80	1.88		Con. Outlet
Locomobile	Single Shell	$5\frac{1}{2}$"	$23\frac{1}{2}$"	406	558	$1\frac{3}{8}$" S	$1\frac{3}{16}$"	4 cyl.	251	2.20	1.38	1.00	
Maxwell	Concentric	4"	30"	377	377	1" I		2 cyl.	100.5	3.80	1.00		Con. Outlet
Merdedes		7"	30"	660	1155	$1\frac{1}{2}$" S	$\frac{7}{8}$" S	4 cyl.	418.	2.55	1.75	.34	Con. Outlet
G. Mercedes		7"	29"	638	1118	2" I	1" S				1.85	.25	Con. Outlet
Northern	2 Shells in Series	5"	40"	1258	1570	$1\frac{1}{4}$" I		2 cyl.	206.	7.65	1.25		Con. Outlet
Oldsmobile	Concentric	$4\frac{1}{2}$"	31"	438	493	$1\frac{1}{4}$" I	$\frac{3}{4}$"				1.13	.36	
Packard '05	Concentric	6"	15"	289	442		$\frac{3}{4}$" S	4 cyl.	302.	1.46	1.52		Con. Outlet
Packard '06		8"	28"	704	1415	3" I	$1\frac{1}{4}$" I	4 cyl.	334.	4.23	2.02	.17	

SUMMARY of DATA on MUFFLERS

Muffler						Piping		Motor		Ratios			Remarks
Kind	Type	Width	Length	R, rad Sur. in □"	V, vol. in cu. in	Inlet	Outlet	Type	Total Vol., v	$\frac{V}{v}$	$\frac{V}{R}$	$\frac{Outlet}{Inlet}$	
Peerless	Baffle	7"	24"	528	924	2" S	$\frac{5}{8}$"	4 cyl.	318	2.9	1.74	.10	Corr. Outlet
Pope-Toledo	'06 Concentric	7"	$30\frac{1}{2}$"	671	1172	$1\frac{1}{2}$" S	1" S	4 cyl.	408	2.87	1.74	.44	
Pope-Toledo	'05 Concentric	8"	28"	704	1415	$1\frac{3}{16}$" S	$42-\frac{3}{16}$" Holes	4 cyl.	207.	6.85	2.02	1.05	
Queen	Concentric	6"	18"	346	530	$1\frac{3}{16}$" S	1" I	4 cyl.			1.53	.71	
Renault	Concentric	7"	32"	704	1231	$1\frac{1}{4}$" I	$1\frac{3}{16}$" S	4 cyl.			1.75	.90	Corr. Outlet
Stearn	Concentric	6"	24"	462	708	$1\frac{7}{8}$" S	$1\frac{7}{8}$" S	4 cyl.			1.53	1.00	
Stoddard Dayton	Concentric	$5\frac{3}{4}$"	24"	433	624	$1\frac{1}{2}$" S	$\frac{7}{8}$" S	4 cyl.	318	1.96	1.42	.34	
Welch	Concentric	8"	24"	603	1212	2" I	$1\frac{1}{4}$" I	4 cyl.	373	3.24	2.01	.39	
Winton	Baffle	$6\frac{1}{2}$"	24"	490	796	$1\frac{3}{4}$" S	$1\frac{1}{4}$" I	4 cyl.	355	2.25	1.63	.51	

DATA OF MUFFLER COMPETITION TESTS OF AUTOMOBILE CLUB OF FRANCE

1903

Name of Muffler	Weight in lbs.	Degree of Noiselessness	Output in Watts of Motor	Output in H.P.	% Loss due to Muffler Backpressure
Without Muffler		0	5676	7.6	0
Ossant-Freres	22	12	5040	6.75	11.2
De Retz	42	12	4950	6.65	12.8
Motor Car	16.2	12	4500	6.04	20.7
Rousseau	—	11	5220	6.98	8.
Megevet	—	10	5220	6.98	8.
St. Denis	—	10	5310	7.12	6.4
Linzeler	—	10	4680	6.27	17.5
Arnaud	—	8	5175	6.94	8.8
Chapuis	—	13	4140	5.54	27.

1905

Make	Eliminating Trials			Final Tests		
	Degree of Noiselessness	Volts	Amp.	Output in H.P	Loss in H.P.	% Loss due to Muffler Backpressure
Without Muffler	0	90	62	7.70		
Chapuis	13	90	46			
Ossant Freres	12	90	50	6.84	.86	11.1
De Retz	12	90	55	6.72	.98	12.2
Motor Car	12	90	50	6.11	1.59	20.6
Ossant Freres	11	90	56	6.84	.86	11.1
Rousseau	11	90	58			
Megevet	10	90	57			
St. Denis	10	90	59			
Ravel	10	90	52			
Arnaud	8	90	57.5			

DATA and RESULT SHEET.
TEST Nº 1.

Without Muffler.					With Burr Muffler.						
Backpressure in lbs/sq. in."	Temp. Gas in °F	R.P.M.	Load	B.H.P.	B.H.P.	Loss in B.H.P.	Loss in %	Backpressure in lbs/sq. in."	Temp. Exhaust degree F.	R.P.M.	Load.
.3	790	313	26.5	8.22	8.24	- .02	-.243	1.4	805	310	26.8
.2	725	288	30.	8.88	6.30	2.58	29.1	1.2	705	212	30.
.25	760	310	25.	7.67	7.71	- .04	-.5.23	1.1	810	312	25.
.3	750	311	26.	8.00	8.03	- .03	-.375	1.1	795	312	26.
.35	770.	312	26.9	8.30	8.24	.06	.725	1.1	775 ?	310	26.9
.35	805	310	27.9	8.60	8.64	- .04	-.465	1.	795 ?	312	27.9
.3	800	312	28.2	8.70	8.54	.16	1.84	.8	840 ?	307	28.2
.3	790	309	28.5	8.73	8.8	- .07	- .84	1.	815	313	28.5
.35	800	305	29.	8.79	8.81	- .02	- .23	.7	830	306	29.
.3	835	308	29.2	8.93	8.96	- .03	- .33	.75	840	309	29.2
.35	840	300	29.7	8.82	8.37	.45	5.11	.8	830	282	30.1
.3	750	310	30.1	9.25	9.4	- .15	- 1.62	.7	810	312	30.1
.3		304	30.5	9.2	9.3	- .10	- 1.09	.8		307	30.5
.3		300	30.9	9.2	8.87	.33	3.58	.75		289	30.9

DATA and RESULT SHEET.
TEST № 2.

per Explos.

Exhaust.	E.P.M.	R.P.M.	Load	B.H.P.	B.H.P. per Explosion.	Loss in B.H.P.	Loss in %.	Backpressure in lbs per sq in.
Burr Muffler	134	304	29.7	8.95	.0664 .0667	.0003	.45	1.5
Open	137	310	29.7	9.12	.0667 .0664			.3
Open	134	306	29.7	9.	.067	.003	4.47	.35
Burr Muffler	139	304	29.7	8.92	.0642			1.4
Burr Muffler	144 134	302	29.7	8.85	.0615 .0660	.0073	10.6	1.4
Open	133	312	29.7	9.16	.0688			.3
Open	132	310	29.7	9.1	.069	.002	2.9	.3
Burr Muffler	135	308	29.7	9.06	.067			1.4
Burr Muffler	136	312	29.7	9.08	.0667	.0013	1.91	1.4
Open	133	310	29.7	9.05	.068			.3
Burr Muffler	134	306	20.	6.07	.0453	.0032	6.6	
Open	129	308	20.	6.26	.0485			
Open	129	302	20.	5.97	.0463	-.0009	-1.94	
Burr Muffler	131	313	20.	6.2	.0472 .0473			
Burr Muffler	108	313	20.	6.17	.0571	0	0	
Open	108	313	20.	6.17	.0571			
Burr Muffler	135	306	25.5	7.86	.0582	.0028	4.6	
Open	127	312	25.5	7.74	.061			
Open	130	312	26.	8.03	.0617	.0016	2.6	
Burr Muffler	134	314	26.	8.08	.0601			

DATA and RESULT SHEET
TEST No. 3.

Exhaust.	E.P.M.	R.P.M.	Load	B.H.P.	B.H.P. per Explosion.	Loss in B.H.P.	Loss in %	Backpressure in lbs. per sq. in.
Moline Muffler	149	304	27.9	8.86	.0594	.0071	10.6	3.0
Open	133	305	27.9	8.86	.0665			0.4
Open	134	304	27.9	8.86	.0661	.0077	11.6	0.4
Moline Muffler	150	300	27.9	8.75	.0584			3.0
Moline Muffler	138	275	27.9	8.05	.0583	.0065	10.1	3.0
Open	136	299	27.9	8.75	.0648			0.4
Open	133	304	27.9	8.86	.0665	.0064	9.61	0.4
Moline Muffler	147	303	27.9	8.86	.0601			3.0
Moline Muffler 3/4" Pipe Outlet	143	302	27.9	8.8	.0615	.0046	7.	3.8
Open	134	304	27.9	8.86	.0661			0.4
Open	133	304	27.9	8.86	.0665	.0071	10.7	0.4
Moline Muffler 3/4" Pipe Outlet	147	300	27.9	8.75	.0594			3.8
Moline Muffler 3/4" Pipe Outlet	148	302	27.9	8.8	.0595	.0075	11.2	3.5
Open	132	304	27.9	8.86	.067			0.5

DATA and RESULT SHEET.
TEST No 4.

Exhaust	E.P.M.	R.P.M.	Load	B.H.P.	B.H.P. per Explosion.	Loss in B.H.P.	Loss in %	Backpressure. in lbs. per sq. in.
Burr Shell with Nozzle	135	306	27.9	8.93	.066	.0064	8.84	.6
Open	123	306	27.9	8.93	.0724			.25
Open	130	304	27.9	8.86	.0682	.0041	6.01	.2
Burr Shell with Nozzle	138	304	27.9	8.86	.0641			.4
Burr Shell with Nozzle	131	306	27.9	8.92	.0681	-.0005	-0.74	.6
Open	131	304	27.9	8.88	.0676			.6
Burr Shell with Plug	124	287	27.9		Not up to	Speed		.9
Open	132	304	27.9					.4
Open	130	305	27.9	8.87	.0682	.0016	2.35	.4
Burr Shell with Plug	134	304	27.9	8.87	.0661			.8
Burr Shell with Plug	136	303	27.9	8.87	.0651	.0015	2.25	.9
Open	133	304	27.9	8.87	.0666			.4
Burr Shell Unobstructed	133	302	27.9	8.8	.0661	.0015	2.2	.5
Open	131	303	27.9	8.86	.0676			.4
Open	134	304	27.9	8.86	.0667	.0014	2.17	.4
Burr Shell Unobstructed	137	304	27.9	8.86	.0647			.5
Burr Shell Unobstructed	135	304	27.9	8.86	.0656	.0011	1.65	.5
Open	134	305	27.9	8.93	.0667			.3

DATA SHEET.
TEST № 5.

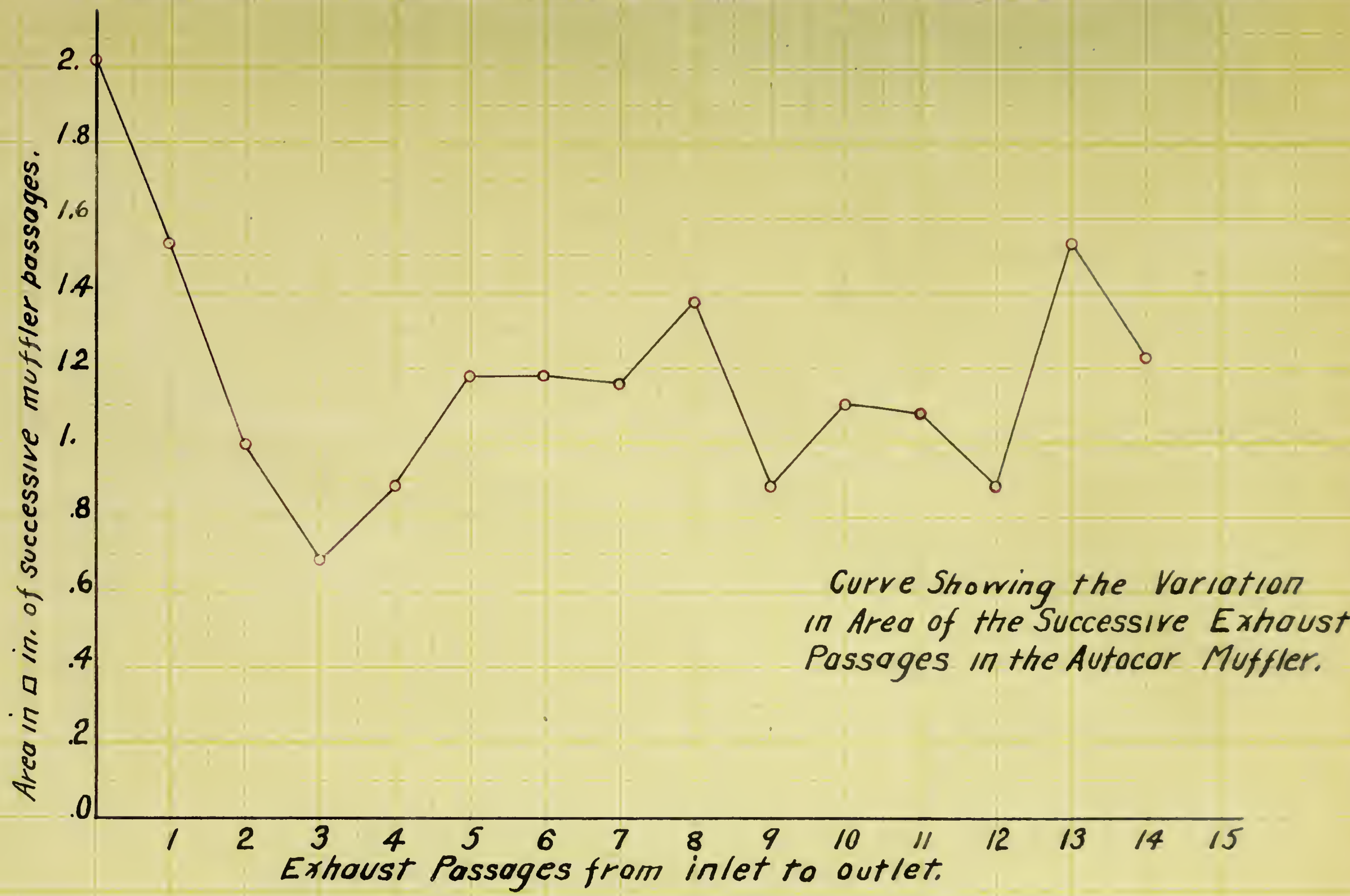
Exhaust.	Backpressurein Lbs.	
	With Pipe.	Without Pipe.
Open	0.9	0.4
Nozzle	2.3	2.5
Burr Shell with Plug	1.4	0.9
Burr Shell Unobstructed	1.1	0.5
Moline Muffler	2.9	3.0
Moline Muffler $\frac{3}{4}$" Pipe Outlet	3.4	3.8

DATA and RESULT SHEET
TEST № 6

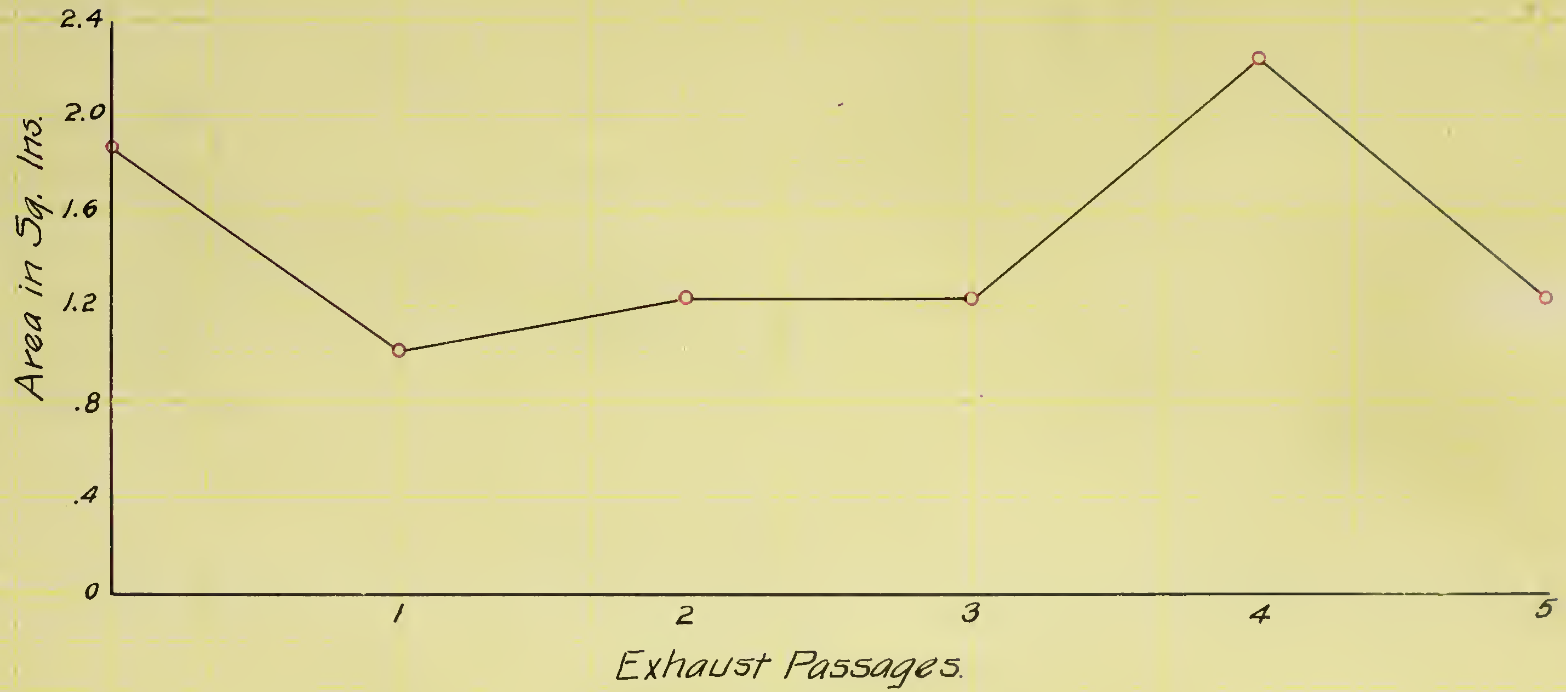
Exhaust	R.P.M.	Load Lbs.	B.H.P.	Backpressure in Lbs. per Sq. In. From Pumping Diagrams	Backpressure in Lbs. per Sq. In. From Manometer
Open	312	0	0	0.7	.75
Open	313	0	0	.6	.8
Open	312	6⅔	2.06	.5	.6
Open	320	6⅔	2.11	.4	.7
Open	315	13⅓	4.15	.6	.5
Open	320	13⅓	4.22	.65	.4
Open	312	20	6.18	.7	.5
Open	315	20	6.24	.9	.5
Open	314	26⅔	8.29	.75	.4
Open	312	26⅔	8.24	.75	.5
	Average			.65	.52
Burr Muffler	313	0	0	2.1	2.
Burr Muffler	312	0	0	2.15	1.8
Burr Muffler	312	6⅔	2.06	1.7	1.5
Burr Muffler	312	6⅔	2.06	2.8	2.2
Burr Muffler	312	13⅓	4.12	1.8	1.7
Burr Muffler	318	13⅓	4.20	1.7	2.1
Burr Muffler	315	20	6.24	1.95	1.4
Burr Muffler	315	20	6.24	2.2	1.6

DATA and RESULT SHEET
TEST No 6

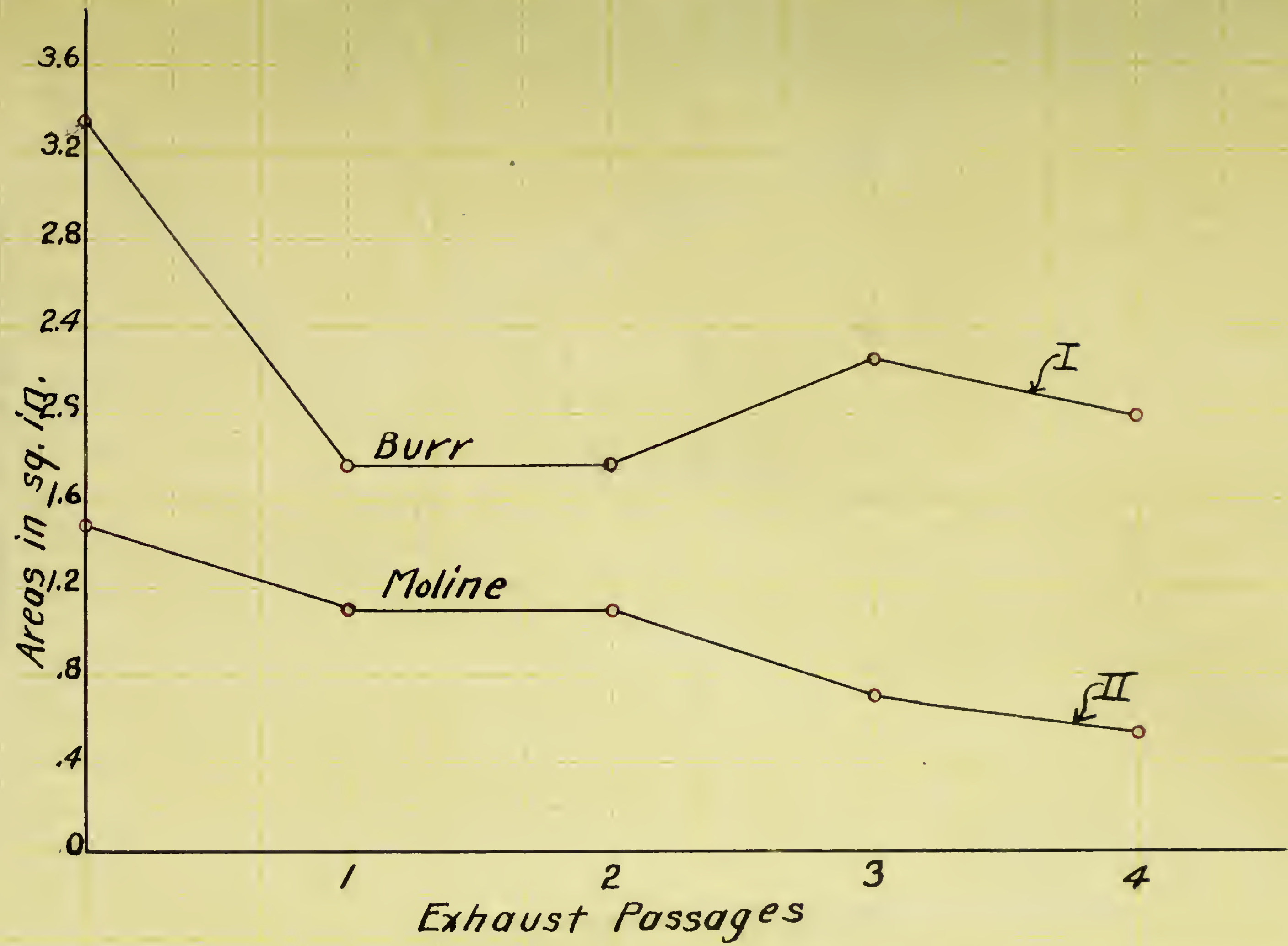
Exhaust	R.P.M.	Load Lbs.	B.H.P.	Backpressure in Lbs. per Sq. In.	
				From Pumping Diagrams	From Manometer
Burr Muffler	314	$26\frac{2}{3}$	8.29	1.85	0.9
Burr Muffler	312	$26\frac{2}{3}$	8.24	3.60	1.2
	Average			2.2	1.6
Moline Muffler	314	0	0	9.06	6.0
Moline Muffler	316	0	0	5.75	5.0
Moline Muffler	320	$13\frac{1}{3}$	4.22	6.35	4.7
Moline Muffler	318	$13\frac{1}{3}$	4.20	5.4	4.1
Moline Muffler	314	20	6.21	5.7	3.8
Moline Muffler	314	20	6.21	5.9	4.1
Moline Muffler	313	$26\frac{2}{3}$	8.26	6.0	3.9
Moline Muffler	312	$26\frac{2}{3}$	8.24	7.6	5.2
	Average			6.15	4.3
Both Mufflers	314	0	0	1.45	1.5
Both Mufflers	315	0	0	1.35	1.4
Both Mufflers	318	$13\frac{1}{3}$	4.20	1.2	1.2
Both Mufflers	320	$13\frac{1}{3}$	4.22	0.9	1.1
Both Mufflers	314	20	6.21	1.6	0.8
Both Mufflers	314	20	6.21	1.4	1.1
Both Mufflers	314	$26\frac{2}{3}$	8.29	1.25	0.9
	Average			1.27	1.03


Area in □ in. of successive muffler passages.
2.
1.8
1.6
1.4
1.2
1.
.8
.6
.4
.2
.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Exhaust Passages from inlet to outlet.
Curve Showing the Variation in Area of the Successive Exhaust Passages in the Autocar Muffler.

Curve No. 1

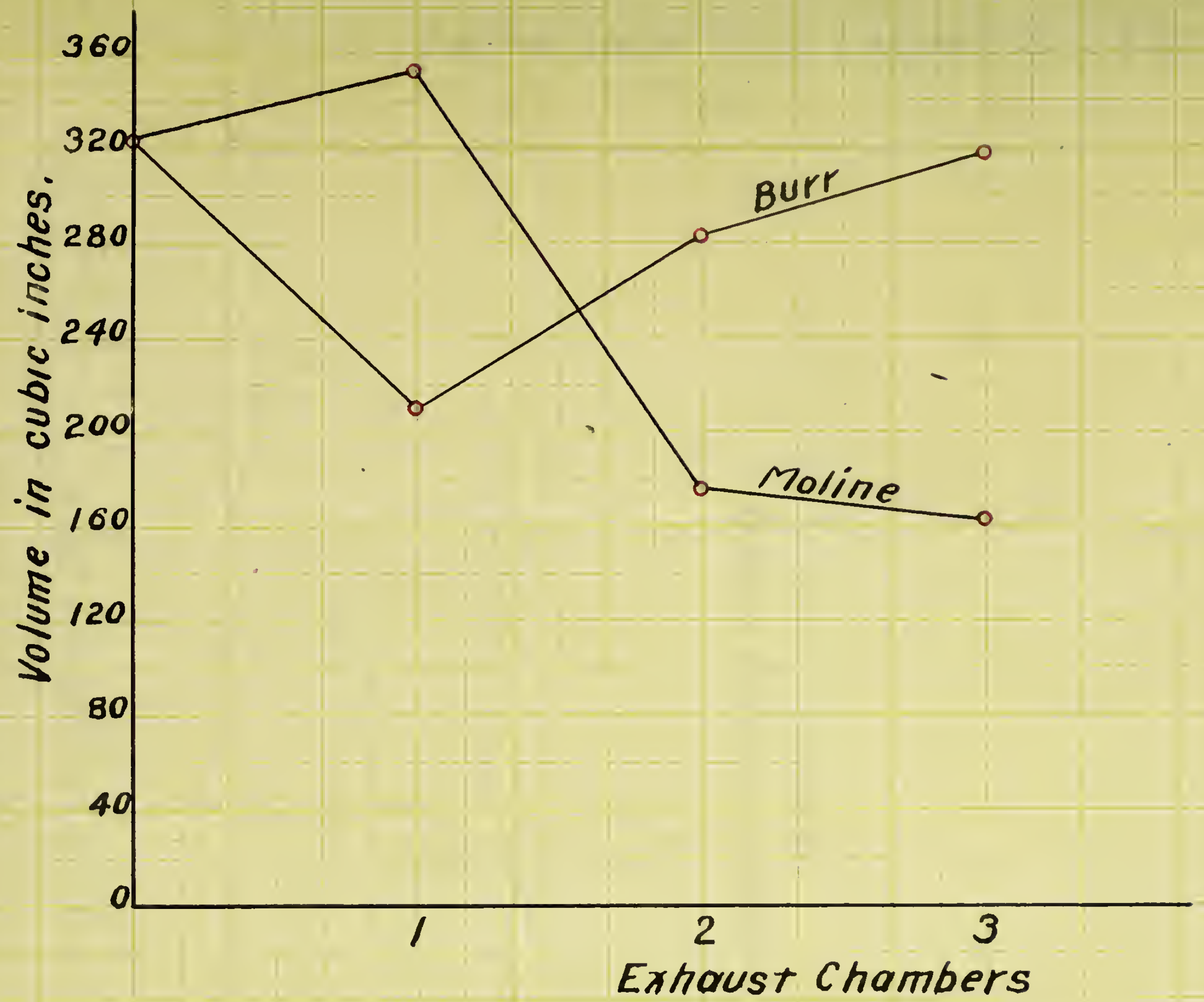


Curve № 2
CURVE SHOWING THE VARIATION IN
AREA OF THE SUCCESSIVE EXHAUST PASSAGES
IN THE LOCOMOBILE MUFFLER.



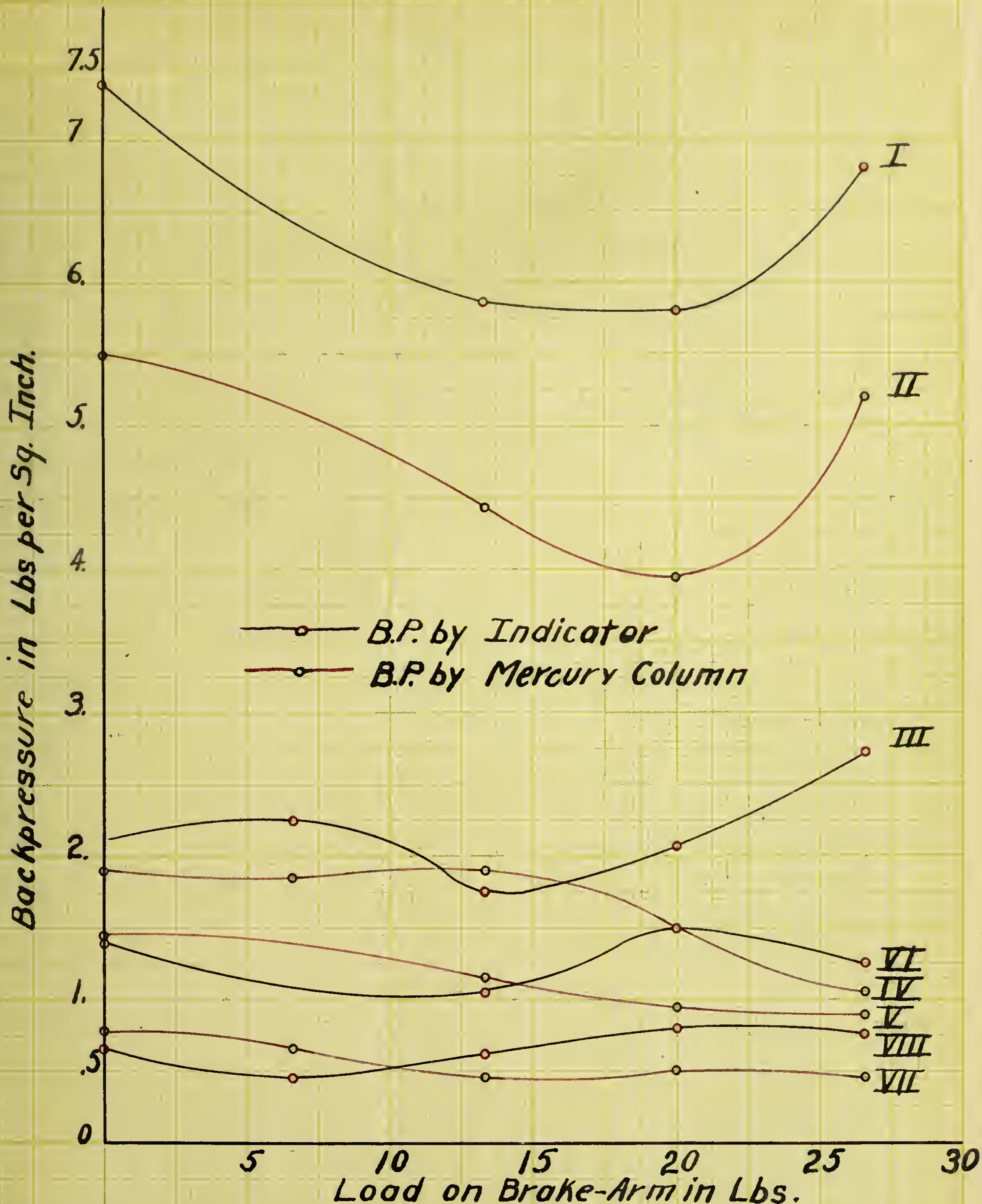
Curve № 3

Curves Showing the Variation in Area of the Successive Exhaust Passages in,
I. Burr Muffler.
II Moline "



Curve № 4

Curves Showing the Successive
Expansion Volumes, in
I Burr Muffler
II Moline Muffler



Curves Showing Variation in Backpressure

Curve No 5

I + II Moline Muffler

III + IV Burr Muffler

V + VI Both Mufflers

VII + VIII Exhaust Open to Air.